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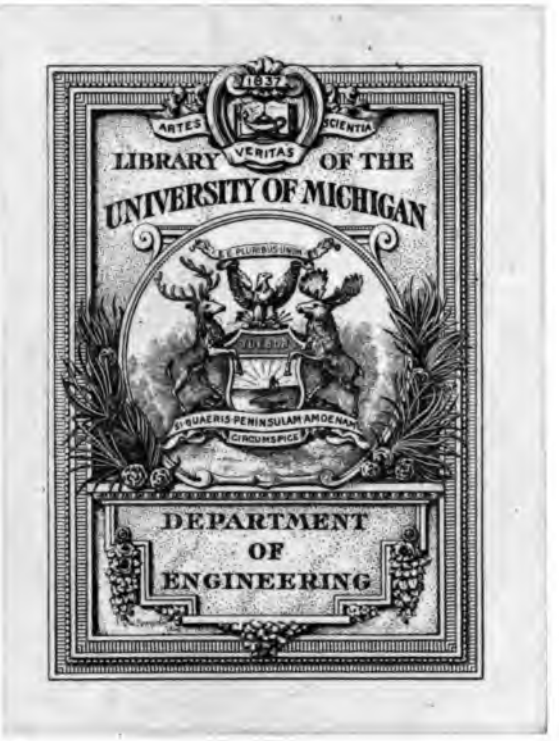
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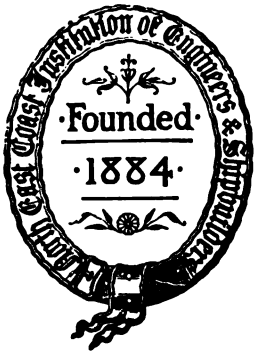

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VOLUME VII.

SEVENTH SESSION, 1890-91.

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1891.

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ERRATA.

Page 189, line 19, *for* "Table III." *read* "Table VI."

Page 191, Table VII., col. 1, *for* "No. in Table II." *read* "No. in Table V."

Page 192, line 27, *for* "Table I." *read* "Table IV."

Page 324, line 6, *for* "electrical engineering," *read* "electrical lighting."

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CONTENTS OF VOLUME VII.

Seventh Session, 1890-91.

	PAGE.
Alphabetical List of Names of Writers of Papers and Speakers	viii
List of Publications Received	xii
Library Catalogue	xviii
List of Officers, 1890-91	xxiii
„ Committees, etc., 1890-91	xxiv
„ Honorary Members, Life Members, and Associates, July, 1891	xxv
„ Members, July, 1891	xxv
„ Associates „	xliii
„ Graduates „	xlvi
Memoirs	xlix
Constitution and Bye-Laws	li
Library and Reading Room Bye-Laws	lxiii
Proceedings at General Meetings ... 1, 41, 73, 125, 167, 197, 237, 267, 315, 365, 403	
Council Report for Sixth Session	5
Financial Statement „	8
Donations	11
Proceedings at Closing Business Meeting	437
Visit to Tudhoe Ironworks and Colliery	440

PAPERS READ DURING THE SESSION.

1890.

Oct. 13th.—President's Inaugural Address, by Mr. Wigham Richardson 17

Vote of thanks to President for his Address 36

Nov. 21st.—"Increased Boiler Pressure and Increased Piston Speed for Marine Engines," by Mr. W. R. Cummins 47

Discussion 60

Dec. 15th.—Discussion continued 77

1891.

Jan. 10th.—Discussion continued 149

Mr. W. R. Cummins's Reply 151

1890.

Dec. 15th.—"The Unsinkability of Cargo-Carrying Vessels" (First Paper), by Mr. W. Hök 87

Appendices 102

Discussion 107

1891.

Jan. 10th.—Discussion continued—Communication from Mr. L. Piaud ... 139

Feb. 2nd.—Mr. W. Hök's Reply 169

1890.

Dec. 15th.—"Main Steam Pipes," by Mr. M. Sandison 113

Discussion 119

1891.		PAGE.
Feb. 2nd.	—Discussion continued	175
	Mr. M. Sandison's Reply	176
Jan. 10th.	—"Mechanical Aid to the Investigation of Experimental Curves," by Mr. J. Denholm Young	127
	Discussion	135
	Mr. J. D. Young's Reply	137
Feb. 2nd.	—"Screw Propeller: The Influence of the Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance," by Mr. A. Blechynden	179
„ 20th.	—Discussion	199
March 9th.	—Discussion continued	239
	Mr. A. Blechynden's Reply	241
Feb. 20th.	—"The Strength of Short Flat-Ended Cylindrical Boilers," by Mr John T. Nicolson	205
	"Results of Experiments on the Strength of Boilers," by Mr. J. C. Spence	219
	Appendix	225
March 9th.	—Discussion	249
	Communication from Mr. J. F. Walliker	255
	Mr. J. C. Spence's Reply	257
„ 23rd.	—"Electrical Engineering, with Special Reference to Electric Lighting," by Mr. W. C. Mountain	269
	Appendix A.—The St. James and Pall Mall Electric Light Co. ...	297
	Appendix B.—Deptford Central Station, London	302
	„ Electric Lighting Newcastle-upon-Tyne	305
	Discussion	306
April 10th.	—Discussion continued	319
	Mr. W. C. Mountain's Reply	325
	"The Unsinkability of Cargo-Carrying Vessels" (Second Paper), by Mr. W. Hök	335
	Appendix A	355
	Appendix B	359
	Discussion	360
„ 25th.	—Discussion continued	367
May 11th.	—Mr. W. Hök's Reply	405
April 25th.	—"Water-Gauge Fittings for Steam Boilers," by Mr. Harry Gray	373
	Discussion	383
May 11th.	—Mr. Harry Gray's Reply	411
April 25th.	—"The Basis of Ships' Scantlings," by Mr. J. Petree	393
	Discussion	396
	Discussion continued	417
	Mr. J. Petree's Reply	427
	Communication from the President (Mr. Wigham Richardson) on Mr. J. Petree's Paper	430

LIST OF PLATES.

PLATES TO ILLUSTRATE PAPER ON—	PLATES.
"Increased Boiler Pressure and Increased Piston Speed for Marine Engines"	I. to VI.
"The Unsinkability of Cargo-Carrying Vessels" (First Paper)	VII. to XII.
"Main Steam Pipes"	XIII., XIV., and XIX.
"Mechanical Aid to the Investigation of Experimental Curves"	XV. to XVIII.
"The Influence of the Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance"	XX. to XXIII.
"The Strength of Short Flat-Ended Cylindrical Boilers"	XXIV.
"Results of Experiments on the Strength of Boilers"	XXV and XXVI.
"Electrical Engineering. with Special Reference to Electric Lighting"	XXVII. to XXXIX.
"The Unsinkability of Cargo-Carrying Vessels" (Second Paper)	XL. to XLVII.
"Water-Gauge Fittings"	XLVIII. to LIV.
Communication from Mr. Wigham Richardson (President) on "The Basis of Ships' Scantlings" ...	LV.

ALPHABETICAL LIST OF WRITERS OF PAPERS AND SPEAKERS.

NAME.	TITLE OF PAPER OR SUBJECT UNDER DISCUSSION.	PAGE.
Allan, J. M.	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	69
Arnison, G. N., Jun. ...	Communication on Increased Boiler Pressure and Increased Piston Speed for Marine Engines ..	149
„	Electrical Engineering, with Special Reference to Electric Lighting...	324
Blechynden, A.	SCREW PROPELLER: THE INFLUENCE OF THE RELATIVE DIMENSIONS AND PROPORTIONS OF THE SCREW PROPELLER ON THE VESSEL'S PERFORMANCE	179
„	Reply to the Discussion on the Influence of the Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance ...	241
Boyd, W.	Vote of Thanks to President for Inaugural Address...	36
„	Vote of Thanks to President	438
Brown, E.	Electrical Engineering, with Special Reference to Electric Lighting...	312
Broughton Copper Co. ...	Communication on Main Steam Pipes	121
Buckland, H. B. ...	Communication on Increased Boiler Pressure and Increased Piston Speed for Marine Engines ..	77
Courtier-Dutton, W. T...	The Basis of Ships' Scantlings	401
Cummins, W. R. ...	INCREASED BOILER PRESSURE AND INCREASED PISTON SPEED FOR MARINE ENGINES ...	47
„	Reply to Discussion on Increased Boiler Pressure and Increased Piston Speed for Marine Engines ...	151
De Rusett, E. W. ...	The Unsinkability of Cargo-Carrying Vessels (First Paper)	109
Doxford, W. T.	Vote of Thanks to President for Inaugural Address	39
„	Electrical Engineering, with Special Reference to Electric Lighting...	333
„	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	360,363
English, Lieut.-Col. ...	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	69
Fothergill, J. R. ...	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	65
„	The Unsinkability of Cargo-Carrying Vessels (First Paper)	143
„	Water-Gauge Fittings for Steam Boilers	389
Gravell, J.	The Unsinkability of Cargo-Carrying Vessels (First Paper)	169

NAME.	TITLE OF PAPER OR SUBJECT UNDER DISCUSSION.	PAGE.
Gravell, J.	The Basis of Ships' Scantlings	423
Gray, H.	Electrical Engineering, with Special Reference to Electric Lighting...	311
„	WATER-GAUGE FITTINGS FOR STEAM BOILERS ...	373
„	Reply to Discussion on Water-Gauge Fittings for Steam Boilers	411
Hall-Brown, E.... ...	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	60,68
„	The Influence of the Relative Dimensions of the Screw Propeller on the Vessel's Performance ...	199
„	Water-Gauge Fittings for Steam Boilers	387
Hök, W.	THE UNSINKABILITY OF CARGO-CARRYING VESSELS (First Paper)	87
„	Reply to Discussion on the Unsinkability of Cargo-Carrying Vessels	169
„	The Influence of the Relative Dimensions of the Screw Propeller on the Vessel's Performance ...	201
„	THE UNSINKABILITY OF CARGO-CARRYING VESSELS (Second Paper)	335
„	Reply to the Discussion on the Unsinkability of Cargo-Carrying Vessels (Second Paper) ...	405
„	The Basis of Ships' Scantlings	418
Holmes, J. H.	Electrical Engineering, with Special Reference to Electric Lighting	308
Johnson, J.	The Unsinkability of Cargo-Carrying Vessels (First Paper)	108
Kilvington, W.	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	80
Laing, A.	Sub-Committee of Lloyd's Register	14
Leckie, A.	The Unsinkability of Cargo-Carrying Vessels (First Paper)	142
MacColl, Hector ...	Results of Experiments on the Strength of Boilers...	252
McGlashan, A.	The Unsinkability of Cargo-Carrying Vessels (First Paper)	143
„	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	367
„	The Basis of Ships' Scantlings	399
Macoll, Hugh	Chair of Engineering and Naval Architecture in Durham College of Science	43
„	The Unsinkability of Cargo-Carrying Vessels (First Paper) ... ...)	107,109, 146
„	Mechanical Aid to the Investigation of Experimental Curves	137
„	Main Steam Pipes	177
„	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	360
„	The Basis of Ships' Scantlings	398
Marshall, F. C.	Installation of President	1
„	Vote of Thanks to President for Inaugural Address	37
„	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	84
„	Main Steam Pipes	122
„	The Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance ...	247
„	The Strength of Short Flat-ended Cylindrical Boilers	249
„	Results of Experiments on the Strength of Boilers...	265

Name.	Title of Paper or Subject under Discussion.	Page.
Marshall, F. C.	Vote of Thanks to President	439
Menzies, W.	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	372
Morrison, W.	Electrical Engineering, with Special Reference to Electric Lighting...	324
Mountain, W. C. ...	Electrical Engineering, with Special Reference to Electric Lighting	269
„	Reply to Discussion on Electrical Engineering, with Special Reference to Electric Lighting... ...	325
Mudd, T.	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	372
„	Water-Gauge Fittings for Steam Boilers	383
Myles, D.	The Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance ...	240
Newitt, L.	Electrical Engineering, with Special Reference to Electric Lighting...	319
Nichol, B. G.	The Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance...	239
„	Results of Experiments on the Strength of Boilers...	257
„	Electrical Engineering, with Special Reference to Electric Lighting...	323
„	Water-Gauge Fittings for Steam Boilers	387
Nicolson, J. T.	The Strength of Short Flat-ended Cylindrical Boilers	205
Patterson, James ...	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	78
Petree, J.	The Basis of Ships' Scantlings	393
„	Reply to the Discussion on the Basis of Ships' Scantlings...	427
Phillips, T.	Mechanical Aid to the Investigation of Experimental Curves	136
„	The Unsinkability of Cargo-Carrying Vessels (First Paper)	143
„	The Basis of Ships' Scantlings	396
Piaud, L.	Communication on the Unsinkability of Cargo-Carrying Vessels (First Paper)...	139
Price, J....	Vote of Thanks to President for Inaugural Address	38
Richardson, Wigham ...	Adoption of Council's Report...	14
„	Inaugural Address	17
„	Reply to Vote of Thanks	39
„	The Chair of Engineering and Naval Architecture in the Durham College of Science	43
„	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	71
„	The Basis of Ships' Scantlings	417,423
„	Communication on the Basis of Ships' Scantlings ...	430
Sandison, M.	Main Steam Pipes	113
„	Reply to Discussion on Main Steam Pipes	176
„	Electrical Engineering, with Special Reference to Electric Lighting...	319
Seaman, C. J.	Water-Gauge Fittings...	390
Seaton, A. E.	Communication on Main Steam Pipes	120

NAME.	TITLE OF PAPER OR SUBJECT UNDER DISCUSSION.	PAGE.
Spence, J. C.	RESULTS OF EXPERIMENTS ON THE STRENGTH OF BOILERS	219
„	Reply to Discussion on the Results of Experiments on the Strength of Boilers	257
Stirzaker, J. C.... ...	Mechanical Aid to the Investigation of Experimental Curves	136
„	Results of Experiments on the Strength of Boilers...	249
Stoddart, J. E.	Water-Gauge Fittings...	386
Taylor, A.	Main Steam Pipes	176
Thompson, R.	Investment of Funds	15
„	The Chair of Engineering and Naval Architecture in the Durham College of Science	44
„	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	64
Thomson, J., Jun. ...	Mechanical Aid to the Investigation of Experimental Curves	135
„	The Unsinkability of Cargo-Carrying Vessels (First Paper)	145
„	Electrical Engineering, with Special Reference to Electric Lighting...	306
„	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	362
Walliker, J. F.	Main Steam Pipes	175
„	Communication on the Results of Experiments on the Strength of Boilers	255
„	Electrical Engineering, with Special Reference to Electric Lighting...	312
Weighton, R. L. ...	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	81
„	Electrical Engineering, with Special Reference to Electric Lighting...	306,313
Westgarth, T.	Increased Boiler Pressure and Increased Piston Speed for Marine Engines	62,68
„	Water-Gauge Fittings...	385
Yeoman, F.	The Unsinkability of Cargo-Carrying Vessels (Second Paper)	369
Young, J. D.	MECHANICAL AID TO THE INVESTIGATION OF EXPERIMENTAL CURVES...	127
„	Reply to Discussion on Mechanical Aid to the Investigation of Experimental Curves	137

LIST OF PUBLICATIONS RECEIVED.

TRANSACTIONS OF INSTITUTIONS.

SUMMARY OF CONTENTS.

TRANSACTIONS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, New York, *Vol.* XI., 1890.—Tables of the Properties of Steam. Cost of Steam and Water Power. Cost of Lubricating Car Journals. Philosophy of the Multi-Cylinder or Compound Engine. Flow of Steam through Orifices. Experimental Study of the Errors of Different Types of Calorimeters. Rolling Steel Rails. Steam Pipes for Collieries. Indicator Rigging for Compound Engines. A New Recording Pressure Gauge. How to Use Steam Expansively in Direct-Acting Steam Pumps. Street Car Gear for Modern Speeds. Graphical Analysis of Reciprocating Motion. Methods of Reducing the Fire Loss. The Comparison of Indicators. The Influence of the Steam Jackets on the Pawtucket Pumping Engine. The Performance of a Double Screw Ferry Boat. Theory and Design of Chimneys. General Solution of the Transmission of Force in a Steam Engine as Influenced by the Action of Friction, Acceleration, and Gravity. Appendix to Report of Committee of Standard Tests. Report of Committee on a Standard Method of Conducting Duty Trials of Pumping Engines. Hirn and Dwelshauver's Theory of the Steam Engine. Determination of the Sensitiveness of Automatic Sprinklers. Test of Several Types of Engines under Conditions found in Actual Practice. Péclets Treatment of Chimney Draught. The Mechanical Theory of Chimney Draught. A Universal Steam Calorimeter. Memoranda Regarding the Indicating of the Engines of the Steamer "City of Richmond." Test of a Refrigerating Plant. Working Railroads by Electricity. Efficiency of Locomotives. An Open Mercury Column for High Pressures. Heating Furnaces. Equilibrium Arch Curves. Comparative Test of a Hot Water and Steam Heating Plant. Note on Kerosene in Steam Boilers. The Length of an Indicator Card. Some Experiments with Crane Chains. An Automatic Absorption Dynamometer. The Kinzua Viaduct. Chimney Draught. Tests of Recent Formulæ for Chimney Draught. The Graphic Representation of Thermal Quantities. On the Measurement of Durability of Lubricants. The Effective Area of Screws. The Effect of an Unbalanced Eccentric or Governor Ball on the Valve Motion of Shaft-Governed Engines. A Use for Inertia in Shaft Governors. A Governor for Steam Engines.

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Shafting and Couplings. Some Forms of Propellers. Graduates' Papers :—Foundations. Some Recent Improvements in Marine Boilers. Marine Engines.

JOURNAL OF THE IRON AND STEEL INSTITUTE, London, *No.* 1, 1890.—A new form of Siemens Furnace. Calculations concerning the possibility of Regenerating the Gas in the new Siemens Furnace. The Critical Points of Iron and Steel. The Carbonisation of Iron by the Diamond. The Changes in Iron produced by the Thermal Treatment. Paper on the Robert-Bessemer Process. Aluminium in Carbonised Iron. Certain Chemical Phenomena in the Manufacture of Steel. The Estimation of Phosphorus in the Basic Siemens Bath. The Rollet Process for producing a Pure Carbide of Iron. *No.* 2, 1890, New York Meeting.—Development of American Blast Furnaces. Notes on the Bessemer Process. On Aluminium Steel. Welding by Electricity. The Wear of Metal. Fuel Gas and some of its Applications. Spirally Welded Steel Tubes. Inspection of Materials of Construction in the United States. Iron Development and Ore Resources of Virginia. Patent Fire-Brick Hot-Blast Stove. Pittsburg International Meeting. Probable Future of the Manufacture of Iron. Protection of Iron and Steel Ships from Foundering. Development of the Marine Engine. Progress of German Practice in the Metallurgy of Iron and Steel since 1876. Darby Process of Recarburisation. Aerial Wire Rope Ways. Iron Ores of the United States. Notes on the Progress of the Home and Foreign Iron and Steel Industries. Fuel in Refractory Material. Production of Pig Iron. Production of Malleable Iron. Forge and Mill Machinery. Production of Steel. Further Treatment of Iron and Steel. Physical Properties. Chemical Properties. Chemical Analysis. Statistics. Bibliography.

JUNIOR ENGINEERING SOCIETY, London, November, 1890.—Address by Prof. Silvanus P. Thompson on Electro-Magnetic Mechanisms.

TRANSACTIONS OF THE LIVERPOOL ENGINEERING SOCIETY, Liverpool, *Vol.* XI., 1890.—Discussion upon some Causes of the Crystallization of Iron. Discussion of Purification of Water and Sewage by the Magnetic Spongy Carbon Process. Stability of Earthen and Masonry Dams. The Salt Industry of Cheshire. Mechanical Refrigeration and Ice-making Machinery. Central Station Electric Lighting. The Efficiency of Gas Engines.

LLOYD'S REGISTER OF BRITISH AND FOREIGN SHIPPING, 2 *Vols.*, 1891-2, and Rules and Regulations.

LIVERPOOL POLYTECHNIC SOCIETY, Session LIII., January-December, 1890.—Liquid Fuel for Marine Boilers. Cameras and Lenses. Mineral Phosphates of South Carolina. Coal Tar and the Modern Application of Coal Tar Products. The Effects of Annealing on Iron after use and on Sheets. Factors of Safety. Electricity Meters.

PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS, London, *No.* 2, 1890.—President's Address on Locomotive Engines. Research Committee on Marine Engine Trials. *No.* 3.—Steel Rails considered Chemically and Mechanically. Recent Improvements in the Mechanical Engineering of Coal Mines. Description of Park Gate Iron and Steel Works. Description of the Loomis Process of Making Gas for Fuel. Description of the Sheffield Water Works. *No.* 4.—On Tube-Frame Goods Wagons of Light Weight and Large Capacity. On Milling Cutters. 1891, *No.* 1.—On some different kinds of Gas Furnaces. On the Mechanical Treament of Moulding Sand.

MANCHESTER ASSOCIATION OF ENGINEERS, Transactions, 1890.—Evaporation of Lancashire Boilers. Continuous Brakes. The Friction and Lubrication of Cylindrical Journals. Feed Water: its Effects on Steam Boilers and its Treatment. Graphic Tabulation and some Relations of Art to Engineering. Automatic Expansion Gear for Steam Engines. Steam Cranes. New Methods of Signalling to Railway Passenger and Slip Coach Arrangement of the Vacuum Automatic Brake. 9th November, 1889.—The Comparative Merits of Main Driving by Spur or Bevel Gearing, Belts or Ropes.

TRANSACTIONS OF THE INSTITUTION OF NAVAL ARCHITECTS, London, *Vol.* XXXI., 1890.—Notes on Recent Naval Manœuvres. The Washington Maritime Conference. Leak Stopping in Steel Ships. Strength of Ships with Special Reference to the Distribution of Sheering Stress over a Transverse Section. Steatite as a Pigment for Anti-Corrosive Paints. The Distribution of Evaporation in a Marine Boiler. System of Combined Steam and Hydraulic Machinery to the Loading, Discharging, and Steering of Ships. The Revolving Engine Applied on Board Ship. The Variation of the Stresses on Vessels at Sea due to Wave Motion. The Spontaneous Ignition of Coal Cargoes. Various Theories of the Screw Propeller. Experiments with Life Boat Models.

PROCEEDINGS OF THE PHILOSOPHICAL SOCIETY, Glasgow, *Vol.* XXI., 1890.—President's Address. Sanitation and Social Economics. Eltrification of Air by Combustion. Notes on Nerve Eels. The Relationship which the Perihelia of Comets bear to the Sun's Line of Flight in Space. On Fiji Past and Present. Some considerations of Asia Minor and Ethnology. The Bassidity of Acids. The Conversion of Ordinary Gas Shades into Regenerative Lamps. The Territorial Expansion of the British Empire during the Last Ten Years. The Alteration of the Index of Refraction of Water with Temperature. On Horticulture. The Hydrostatic Arrangements in the Horse's Foot. Public Lighting by Electricity. The Syanotype Reproductions of Sea Weeds. Club Mosses Past and Present. Reclamation of Waste Lands in the Clyde Estuary. Glimpses in Teutonic Antiquity. Electrical Oscillations.

PROCEEDINGS OF THE SOUTH WALES INSTITUTE OF ENGINEERS, Swansea, *Vol.* XVII., *No.* 1, 1890.—Discussion on Wire Ropes. On a Carbonaceous Mineral or Oil Shale from Brazil. *No.* 2, 1890.—Discussion on Wire Ropes. Large Incandescent Electric Lamp *versus* Arc Lamps. Drainage of Water from Old Mines. Carbonite. South African Coal-field. *No.* 3, April 7, 1891.—Drainage of Water from Old Mines. Carbonite. Miner's Safety-Lamp.

TRANSACTIONS OF THE SOCIETY OF ENGINEERS, London, 1889.—The Construction and Repair of Roads. Fire Proof Floors. Recent Developments in High Explosives. The Forced Percolation of Water through Concrete. Pin-Connected *versus* Riveted Bridges. Modern Gas Engine Practice. Fox's System of Solid-pressed Steel Waggon and Carriage Frames.

PROCEEDINGS OF THE UNITED STATES NAVAL INSTITUTE, Annapolis, M.D., *Vol.* XVI., *No.* 3, 1890.—Navy Boats. The Howell Automobile Torpedo. Desertion and the Bertillon System for the Identification of Persons. Naval Training. *No.* 4.—Protection of the Hulls of Vessels. System of Naval Training and Discipline. The Movements of the Atmosphere. *No.* 5, 1890.—Introduction. Annapolis Armour Test. Report of the Board on the Competitive Trial of Armour-

Plate. Appendix. *Vol.* XVII., *No.* 1, 1891.—Enlistment, Training, and Organisation of Crews for our New Ships. Notes on an Experimental Ammunition Cart. Seacci's Ballistic Equations. Angle of Elevation in order that the Trajectory in Air shall pass through a given point. Target Practice. Electrical Counter and Shaft Revolution and Direction Indicator. *Vol.* XVII., *No.* 2.—Disposition and Employment of the Fleet. On a Method for Calculating the Stability of Ships. High Explosives in Warfare. Proposed Night and Day Signals for the Navy. Electro-Metallurgy. The Samoan Hurricane of March, 1890.

PUBLICATIONS RECEIVED TO DATE, CURRENT NUMBERS OF WHICH LIE ON THE TABLES IN THE READING ROOM:

Electrical Engineer, London.
Electrical Review, London.
Engineering, London.
Indian Engineer, Calcutta, British India.
Indian Engineering, Calcutta, British India.
Industries, London.
Inventions, London.
Iron, London.
Iron and Coal Trades Review, London.
Marine Engineer, London.
Mechanical World, Manchester.
Shipping World, London.
Stahl und Eisen, Düsseldorf.
The Engineer, London.
The Practical Engineer, Manchester.
The Steamship, Leith.
The Illustrated Official Journal of Patents, London.

CATALOGUE OF
BOOKS, TRANSACTIONS, AND PERIODICALS
IN LIBRARY, JULY, 1891.

(1.) TRANSACTIONS OF LEARNED SOCIETIES.

American Society of Mechanical Engineers, New York City, N.Y., Vol. I. to date.

American Society of Naval Engineers, Navy Department, Washington, U.S. of America, Vol. I. to date.

Canadian Society of Civil Engineers, Montreal, Canada, Vol. I. to date.

Civil and Mechanical Engineers, 1888 to date.

Cleveland Institution of Engineers, Middlesbrough, 1889 to date.

Engineering Association, Sydney, New South Wales, Australia, Vol. I. to date.

Engineers and Shipbuilders in Scotland, Glasgow, Vol. IV. and VI. to date.

Genio Civile, Roma, Vol. XXII. to date.

Hull and District Institution of Engineers and Naval Architects, Hull, Vol. I. to date.

Institution of Civil Engineers, London, Vol. LXXIX. to date.

Iron and Steel Institute, London, 1885 to date.

Junior Engineering Society, London, 1886.

Liverpool Engineering Society, Liverpool, Vol. I. to date.

Liverpool Polytechnic Society, Liverpool, 1887 to date.

Manchester Association of Engineers, Manchester, 1883 to date.

Mechanical Engineers, London, 1885 to date.

Midland Institute of Mining, Civil, and Mechanical Engineers, Barnsley, 1884 to date.

Naval Architects' Institution, London, Vols. I. to IX. and XVIII. to date.

North of England Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne, Vol. XXXIV. to date.

North-East Coast Institution of Engineers and Shipbuilders, Vol. I. to date.

Philosophical Society, Glasgow, Vol. XIX. to date.

Royal Dublin Society, Dublin, *Transactions*, Vol. III. to date; *Proceedings*, Vol. IV. to date.

Society of Arts, London, Vol. XXXVII. to date.

Society of Engineers, London, 1884 to date.

Société des Ingenieurs, etc., de Liége, *Bulletin*, 1885 to date; *Annuares*, 1885 to date.

South Wales Institute of Engineers, Swansea, 1884 to date.

United States Naval Institute, Annapolis, Maryland, U.S. of America, 1886 to date.

(2.) TECHNICAL JOURNALS AND PERIODICALS.

Electrical Engineer, London, Vol. III. to date.

Electrical Review, London, Vol. XXIV. to date.

Engineering, London, Vols. IV., V., and VI., XX. and XXI., XXXIV. to date.

Indian Engineer, Calcutta, British India, Vol. VII. to date.

Indian Engineering, Calcutta, British India, Vol. III. to date.

Industries, London, Vol. I. to date.

Inventions, London, Vol. XI. to date.

Iron, London, 1888 to date.

Iron and Coal Trades Review, London, Vol. XXXVI. to date.

Marine Engineer, London, Vol. VII. to date.

Mechanical World, Manchester, 1886 to date.

Shipping World, London, Vol. IV. to date.

Stahl und Eisen, Düsseldorf, Vol. IX. to date.

The Engineer, London, Vol. LIX. to date.

The Mechanics' Magazine, 1864-1866 (3 vols.).

The Practical Engineer, Manchester, Vol. I. to date.

The Practical Mechanics' Journal, 1863 to 1870 (4 vols.).

The Steamship, London, Vol. I. and II.

The Steamship, Leith, Vol. I. to date.

(3.) GENERAL.

(*a.*) Engineering and Mechanical.

Applied Mechanics	Prof. Rankine	1888
Do.	J. H. Cotterill	1890
Boilers and Boiler Making	... N. P. Burgh	1873
Boilers, their Construction and Strength	... T. W. Traill	1888
Bridge Construction	... T. C. Fidler	1887
Bureau of Steam Engineering (U.S.A.), Report of		1889
Bureau Veritas—Report on Steel		1878
Civil Engineering	... Prof. Rankine	1889
Engineering (British Association)	W. Boyd	1889
Engineer's Handbook	T. Reed	1889
Engineering Facts and Figures (2 vols., 1863 and 1864)	... A. B. Brown	1865
Engineering Popularly and Socially Considered (2 copies)	J. W. C. Haldane	1890
Friction and Lost Work in Machinery and Millwork	...R. H. Thurston	1889
Graphic Statics, Principles of	... G. S. Clark	1888
Heat, Treatise on	T. Box	1888
Heat: a Mode of Motion	J. Tyndall	1887
Hydrology, Manual of	... W. Beardmore	1872
Hydraulic Power and Hydraulic Machinery		1887
Iron Bridge Construction (2 vols.)	W. Humber	1870
Iron and Steel Industries, Report on, in Foreign Countries		
Iron Roofs	A. T. Walmsley	1888
Machinery and Millwork	... Prof. Rankine	1887
Manual of Marine Engineering ...	... A. E. Seaton	1889
Manufacture of Iron and Steel, Principles of ...	I. L. Bell	1884
Marine Engineering	W. H. Maw	
Marine Steam Engine	R. Sennett	1885
Materials of Engineering	R. H. Thurston	1884
Mechanical Graphics	G. Halliday	1889
Mechanical Text Book	... Prof. Rankine	1884
Mechanical Engineers' Reference Book ...	N. Foley	1891
Metallurgy of Iron, Treatise on ...	H. Bauerman, F.G.S.	1890
Metallurgy of Steel	H. M. Howe	1890
Metals: Their Properties and Treatment	... C. L. Bloxham	1885
Mill Gearing, etc.	T. Box	1888

Modern Marine Engineering (2 vols.) ...	... N. P. Burgh	1872
Pocket Book on Boilers	.. T. W. Traill	1888
Rules and Tables	... Prof. Rankine	1889
Rules, Tables, and Data for Mechanical Engineers	... D. K. Clark	1890
Screw Propeller	... W. Bourne	1867
Slide Valve	... N. P. Burgh	1868
Spon's Engineers' Price Book	... ...	1888
Steam and the Steam Engine, Text Book on	... A. Jamieson	1889
Steam Engine	G. C. V. Holmes	1890
Do. (4 vols.)	... D. K. Clark	1890
Do.	...J. H. Cotterill	1890
Steam Boilers	... R. Wilson	1879
Steam Engine	... Prof. Rankine	1888
Strength of Materials	... T. Box	1888
Strength of Iron Parts of Steam Machinery	... Van Buren	1869
Strains in Structures	G. A. T. Middleton	1889
Substitution of Metal for Wood in Railway Ties, Report on	... B. E. Fernon	1890
Testing Materials of Construction ...	... W. C. Unwin	1888
Turbine, The	... W. Cullen	1871
Valve Gears	... J. F. Klein	1884

(*b.*) SHIPBUILDING, ETC.

Annals of Lloyd's Register	... ...	1884
Bureau Veritas Register of Shipping	...	1887 to date
German Lloyd's International Register of Shipping ...	...	1891
German Lloyd's Rules and Regulations	...	1891
Lloyd's Register of British and Foreign Shipping (2 vols.)	...	1891
Lloyd's Rules and Regulations	... ...	1891
Modern Shipbuilding and the Men Engaged in it	D. Pollock	1884
Naval Architecture, Manual of	... W. H. White	1889
Naval Annuals	Lord Brassey	1886, 1890, and 1891
Shipbuilding Theoretical and Practical	... Prof. Rankine	1866
Shipbuilding (2 vols.)	... Thearl	1886
Stability of Ships	...Sir E. J. Reed	1885
Stability of Ships	... J. C. Spence	1884
Shipping World Year Book	... ...	1887

(*c.*) ELECTRICAL.

Electricity and Magnetism (2 vols.) ...	... J. C. Maxwell	1881
Elementary Treatise on do.	„	1881

Electric Light Fitting	J. W. Urquhart	1890
Electric Transmission of Energy	G. Kapp	1890
Experimental Researches in Electricity (3 vols.)	M. Faraday	1839
Practical Electrical Measurement ...	J. Swinbourne	1888
Short Lectures to Electrical Artizans ...	J. A. Fleming	1890

(*d.*) MISCELLANEOUS, ETC.

Collieries and Colliers	J. C. Fowler	1869
Duties of Executors	F. W. Dendy	1889
Elements of Projective Geometry	Cremona	1885
Foreign Office List		1886
Geology of England and Wales... ...	H. B. Woodward	1887
Handbook to Industries, N. E. District of England	W. Richardson	1889
Industrial Resources of the Tyne, Wear, and Tees	Lord Armstrong and others	1864
Miscellaneous Scientific Papers...	Prof. Rankine	1881
Practical Treatise on Petroleum	B. J. Crew	1887
River Tyne, History and Resources of... ...	J. Guthrie	1880
Service Chemistry	V. B. Lewes	1889
Water-Gas Plant, a description of	S. Fox	1888
Year Book of Scientific Societies (2 vols.)	1889-90 and 1890-1891	

(*e.*) BIOGRAPHICAL.

Lives of Brindley and others	Smiles	1874
„ Boulton and Watt	„	1878
„ William Denny	A. B. Bruce	1889
„ Metcalf and Telford	Smiles	1874
„ James Nasmyth	„	1885
„ Smeaton and Rennie	„	1874
„ G. and R. Stephenson...	„	1879
„ R. Trevethick	F. Trevethick	1872

(*f.*) DICTIONARIES.

Dictionary of Engineering (4 vols.)	Spon	1874
Dictionary of Terms relating to Iron	A. Tolhausen	1870
French and English Dictionary (2 vols.)	L. Smith & H. Hamilton	1882
German and English Dictionary, Theime-Preusser,	E. Wesseley	
Italian and English Dictionary (2 vols.) ...	Millhouse	
Spanish and English Dictionary (3 vols.) ...	Bustamantes	1890
Technological Dictionary (3 vols.)	A. Tolhausen	1883

LIST OF OFFICERS.

SEVENTH SESSION, 1890-91.

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Past-Presidents:

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FRANCIS C. MARSHALL.

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R. L. WEIGHTON, M.A.

Councilmen:

J. R. FOTHERGILL.	JOHN PRICE.
CHRISTOPHER FURNESS, M.P.	L. RUSDEN.
JOHN GRAVELL.	A. SCHOLEFIELD.
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JOHAN JOHNSON.	J. C. STIRZAKER.
T. MILLAR.	ALEX. TAYLOR.
JAMES PATTERSON.	J. F. WALLIKER.

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WILLIAM BOYD. | W. THEODORE DOXFORD.
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SEVENTH SESSION, 1890-91.

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J. GRAVELL.	L. RUSDEN.
A. LAING.	A. SCHOLEFIELD.
HUGH MACOLL.	B. G. NICHOL (Hon. Treasurer).

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HUGH MACOLL.	J. C. STIRZAKER.
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Representative on Council of Durham College of Science:

WILLIAM BOYD.

Representatives on Sub-Committee of Northumberland County Technical Education Committee:

WILLIAM BOYD. | G. E. MACARTHY.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

List of Members, July, 1891.

EXPLANATION.

(A.)	Agent and Accountant.	(I. & S. M.)	Iron and Steel Merchants and Manufacturers.
(B. B.)	Boiler Builder.	(N. A.)	Naval Architect.
(C. E.)	Civil Engineer.	(R. M.)	Rope Manufacturer.
(D.)	Draughtsman.	(S.)	Shipbuilder.
(E.)	Engineer and Boilermaker.	(S. O.)	Ship Owner.
(E. E.)	Electrical Engineer.	(SUR.)	Engineer & Ship Surveyor.
(F. M.)	Forge Master.		

HONORARY MEMBERS.

		ELECTED.
The Right Hon. Lord Armstrong, C.B., LL.D., F.R.S., Cragside, Rothbury		Nov. 1884
The Right Honourable the Earl of Ravensworth, Ravensworth Castle, near Gateshead-on-Tyne...		Nov. 1884
W. H. White, Esq., The Admiralty, Whitehall, London	(N A)	Nov. 1884

LIFE MEMBERS.

Fox, Samson, Messrs. The Leeds Forge Co., Leeds	(E)	Dec. 1887
Halley, David, Messrs. Burmeister & Wains, Maskin-og Skibsbyggeri, Copenhagen, Denmark...	(E)	Feb. 1887
Macoll, Hugh, 4, Belvedere Road, Sunderland	(S)	Nov. 1884
Pascoe, J. R., Tyrmont, Woodford, Essex	(S)	Dec. 1889
Spence, W. G., Messrs. Gourlay Bros. & Co., Engineers and Shipbuilders, Dundee	(E)	Nov. 1884

LIFE ASSOCIATE.

Eccles, Edward, G, Exchange Buildings, King Street, Newcastle-on-Tyne...	(S O)	Oct. 1887

MEMBERS.

A.

Aberg, Henning, Stora Warfoet, Stockholm, Sweden	(E)	Oct. 1888
Abey, Henry, Fairfield, York Road, West Hartlepool	(E)	Jan. 1889
Adamson, Alex., c/o Messrs. Naval Construction and Armaments Co., Barrow-in-Furness	(S)	Nov. 1885
Ahlbom, C., 11, Sidney Grove, Arthur's Hill, Newcastle-on-Tyne ...	(E)	Nov. 1884
Aitchison, Jas., Hylton, Sunderland	(S)	Nov. 1884

ELECTED.

Alchin, A. H., 89, Wood Lane, Shepherd's Bush, London ... ... (E) Jan. 1885
Allan, Jas. McNeal, 5, Warwick Street, Heaton, Newcastle-on-Tyne (E) Dec. 1886
Allardes, Wm., Greenville Terrace, Bloomfield, Belfast ... ... (E) Nov. 1884
Anderson, J., c/o Messrs. Wigham Richardson & Co., Neptune Works, Walker-on-Tyne ... ... Nov. 1884
Andrew, D., 33, Osborne Road, Jesmond, Newcastle-on-Tyne ...(SUR) Jan. 1885
Andrews, Jas., Drawing Office, Messrs. Naval Construction and Armaments Co., Barrow-in-Furness ... ... (E) Nov. 1884
Anthony, Jas., 6, Northumberland Square, North Shields... ... (S) Oct. 1886
Archbold, Joseph G., c/o Messrs. Blyth Dry Dock Co., Blyth ... (E) Jan. 1889
Armstrong, G. S., 37, Warwick Street, Heaton, Newcastle-on-Tyne (S) Nov. 1884
Armstrong, Robert B., 121, Stratford Road, Heaton, Newcastle-on-Tyne ... ... (E) Oct. 1887
Arnison, Geo., Jun., 61, Fawcett Street, Sunderland (N A & SUR) Nov. 1884
Ash, Mortimer W., 91, Jesmond Road, Newcastle-on-Tyne ... (E) Feb. 1887
Austin, S. P., Wear Dockyard, Sunderland ... ... (S) Nov. 1884
Austin, W. R., Lloyd's Register of Shipping, Royal Exchange, Middlesborough ... ... (E SUR) Oct. 1888

B.

Baguley, Ernest Edwin, 3, Saville Place, Newcastle-on-Tyne ... (E) April 1891
Bailey, James, 3, South Avenue, Ryton-on-Tyne ... ... (E) Nov. 1884
Baines, Geo. Henry, Messrs. Central Marine Engineering Co., West Hartlepool ... ... (E) Oct. 1888
Baird, Robert, 13, Hylton Terrace, North Shields ... ... (E) Jan. 1890
Barclay, James, Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ...(SUR) Nov. 1888
Barley, C. J., 25, Trevor Square, Knightsbridge, London, S.W. ... ... (E) { Graduate, Feb. 1885 / Member, Dec. 1886
Barnett, James Rennie, Lilybank House, Johnston, N.B. ... ... (S) Oct. 1889
Barron, T. G., Fern Villas, Elwick Road, West Hartlepool ... (E) Oct. 1888
Barrow, A. R., N.W. Indian Railways, Sukkur, India ... ... (E) Feb. 1891
Bastow, W. W., 112, Scarborough Street, West Hartlepool ... (S) Dec. 1889
Batey, John Thomas, 25, Harrison Place, Newcastle-on-Tyne ... (S) Nov. 1885
Batliboi, Jehangir Framji, Forjett Street, Tardeo, Bombay ... (E) Dec. 1888
Baxter, J., 26, Simonside Terrace, Heaton, Newcastle-on-Tyne ... (E) Nov. 1884
Beadon, D. C., 29, Beverley Terrace, Cullercoats ... ... (E) Jan. 1885
Beardmore, William, Messrs. Wm. Beardmore & Co., Parkhead Forge, Glasgow ... ... (I & S M) Oct. 1889
Bell, James, Hancock Villa, Weathercock Lane, Low Fell, Gateshead-on-Tyne ... ... (E) Feb. 1887
Bell, William, Roschill Terrace, Roschill, Wallsend-on-Tyne ... (E) Nov. 1888
Bergstrôm, Gus., Poplar Grove, Hart Road, West Hartlepool ... (N A) Mar. 1886
Berkley, A. B., Grange Villa, Jarrow-on-Tyne ... ... (E) Mar. 1887
Berkley, William, c/o Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... (E) Oct. 1889

ELECTED.

Bindesböll, S. C. W., c/o Messrs. Raylton Dixon & Co., Middlesborough ... ... (S) Nov. 1884

Black, Jas., Portobello Foundry, Sunderland ... ... (E) Jan. 1885

Black, J., c/o Messrs. J. Merryweather & Co., West Hartlepool ... (E) Nov. 1888

Black, Wm., Messrs. Black, Hawthorn, & Co., Gateshead-on-Tyne (E) Jan. 1885

Blackie, Thomas Reid, Lloyd's Register of Shipping, Dock Office, West Hartlepool ... ... (SUR) Nov. 1890

Blechynden, Alfred, 12, Cavendish Park, Barrow-in-Furness ... (E) Oct. 1885

Blenkinsop, John N., 38, Ashbornham Grove, Greenwich, S.E. ... (E) Oct. 1885

Blumer, Wm. Riversley, Millum Terrace, Monkwearmouth, Sunderland ... ... (S) Dec. 1886

Boddy, John, 96, Dock Street, Newport, Mon. ... ... (E) Dec. 1888

Bodin, Lauritz M., 27, Argyle Square, Sunderland ... (E & SUR) Dec. 1889

Bond, C. P. W., 27, Leadenhall Street, London, E.C. ... ... (E) Nov. 1888

Bone, W. J., 61, Linskill Terrace, North Shields ... ... (S) Dec. 1884

Bonneyman, James Smith, 13, Ryder Street, Canton, Cardiff ... (E) Nov. 1889

Boolds, Jas. H., c/o Messrs. Raylton Dixon & Co., Cleveland Shipyard, Middlesborough ... ... (S) Oct. 1886

Booth, Arthur Spence, c/o C. Furness, Esq., 85, Water Street, U.S. America ... ... (E) Oct. 1889

Borowski, G., Government Dock Yard, Cherson's Depart., Nicolajeff, Russia ... ... (E) Oct. 1885

Boyd, Wm., North House, Long Benton, Newcastle-on-Tyne ... (E) Nov. 1884

Bramwell, Balfour, 2, Beverley Terrace, Cullercoats (E) {Graduate, Nov. 1886 / Member, Nov. 1887

Brankston, R. T., 36, Hawthorn Street, Newcastle-on-Tyne ... (E) Nov. 1884

Bray, C. H., 19, Frederick Street, Newcastle-on-Tyne ... ...

Brock, John, Exchange Buildings, Cardiff ... ... (E) Nov. 1885

Brown, Eugene, c/o Messrs. J. H. Holmes & Co., Portland Road, Newcastle-on-Tyne ... ... (E E) Feb. 1886

Brown, Robson, Belle Vue Terrace, Tyne Dock ... ... (E) Nov. 1889

Brown, T. R., 110, Roker Avenue, Sunderland ... (E) {Graduate, May 1885 / Member, Oct. 1886

Brown, William, c/o Messrs. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... (E) April 1887

Brown, E. D., Tees Conservancy Commissioners, Graving Dock, Middlesborough ... ... (E) Nov. 1888

Brown, James, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain ... ... (E) Mar. 1891

Browne, Sir B. C., Westacres, Benwell, near Newcastle-on-Tyne (C E) Jan. 1885

Buchanan, A., Michaelson Villa, Barrow-in-Furness ... ... (S) Nov. 1884

Buchanan, John H., Oswald Chambers, 5, Oswald Street, Glasgow (SUR) Oct. 1888

Buckland, H. B., Hamburg Chambers, Quayside, Newcastle-on-Tyne (E) Nov. 1885

Bulmer, John, 1, Graingerville North, Newcastle-on-Tyne ... (E) Mar. 1886

Burdon, J. G., 20, Archbold Terrace, Newcastle-on-Tyne ... ... (E) Nov. 1884

Burns, J., 3, Kaiser Terrace, West Hartlepool ... . Nov. 1884

Butterfield, George, 30, John Candlish Road, Millfield, Sunderland Nov. 1884

ELECTED.

C.

Cama, Nusserwanji Bomanji, Gowala Tank Road, Bombay, British India ... ... (E) Dec. 1888
Cameron, David, 18, Arbroath Road, Dundee ... ... (E) April 1891
Campbell, James J., 2, St. Thomas' Terrace, Newcastle-on-Tyne... (E) Oct. 1888
Cannell, Frank, Messrs. H. Parry & Son, Lisbon ... ... (E & S) Nov. 1887
Carr, J. W. ... ... (E) Feb. 1885
Carstons, Samuel, 57², Wildersgade, Copenhagen ... ... (S) Dec. 1887
Carter, G. J., Elswick Shipyard, Newcastle-on-Tyne ... ... (S) Dec. 1886
Carter, Thos., 49, North Bridge Street, Monkwearmouth, Sunderland (E) Nov. 1884
Casebourne, Charles Baston, Greatham House, Greatham, near West Hartlepool ... ... (E) Dec. 1889
Cay, Arthur, Westoe, South Shields ... ... (E) Nov. 1884
Ceuvel, John L., Kadyk, Amsterdam ... ... (E) Mar. 1886
Chapman, Abel, Capt., Belle Vue, Low Fell, Gateshead-on-Tyne... (E) Nov. 1884
Chapman, Hedley, 147, Park Road, Newcastle-on-Tyne ... ... (E) Feb. 1886
Charlton, Henry, 1, Millfield Terrace, Gateshead-on-Tyne... ... (E) Nov. 1884
Charlton, R. B., Jun., Manors Railway Station Works, Newcastle-on-Tyne ... ... (E) Nov. 1884
Charlton, T., 25, Lincoln Street, Gateshead-on-Tyne ... ... (E) Nov. 1884
Charlton, Thomas, The Cedars, Millhill, West Cowes, Isle of Wight ... ... (E) Nov. 1890
Christie, C. A., 4, Woodside, Tynemouth ... ... (E) Nov. 1884
Christie, C. J. D., Neptune Works, Walker-on-Tyne ... ... (S) Nov. 1884
Christie, J. D., 4, Colbeck Terrace, Tynemouth ... ... (S) Nov. 1884
Churchill, James Dixon, 9, London Street, London, E.C. ... ... (E) Oct. 1889
Clark, Geo., Southwick Engine Works, Sunderland ... ... (E) Nov. 1884
Clark, George, Jun., Southwick Engine Works, Sunderland ... (E) Feb. 1888
Clark, Henry, Southwick Engine Works, Sunderland ... ... (E) Oct. 1887
Clarke, Thos., 82, Rye Hill, Newcastle-on-Tyne ... ... (E) Nov. 1884
Cochrane, James ... ... (E) Nov. 1888
Conning, Alfred C., Dunston Iron & Steel Works, Gateshead-on-Tyne (F M) May 1885
Conràdi, Carl, 5, Prince of Wales Terrace, Hillhead, Glasgow ... (E) Nov. 1884
Consiglio, Luigi, c/o Messrs. Hawthorn, Leslie, & Co., Hebburn-on-Tyne ... ... (N A) Nov. 1890
Cooper, Nusserwanji Naoroji, Indo-China Mills, Sewree, Bombay, India ... ... (E) Oct. 1889
Cooper, William, Baltic Chambers, Quayside, Newcastle-on-Tyne (E) Feb. 1888
Coote, Arthur, Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn-on-Tyne ... ... (S) Nov. 1884
Cornforth, J., Messrs. Gladstone & Cornforth, Church Street, West Hartlepool ... ... (E) Oct. 1888
Cornish, H. P., Lloyd's Register of Shipping, 2, White Lion Court, Cornhill, London, or 2, Lawn Road, Hampstead, London, N.W. (E) Oct. 1888
Courtier-Dutton, W. T., Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ... (S SUR) April 1890
Cowens, William Edward, c/o Messrs. John Abbot & Co., Gateshead-on-Tyne ... ... (E) Dec. 1889

ELECTED.

Craggs, Ernest H., Messrs. R. Craggs & Sons, Middlesborough ... (S) Oct. 1888
Craig, John C., Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ... (E SUR) Oct. 1890
Crawford, Jas., 9, Custom House Court, Quayside, Newcastle-on-Tyne (SUR) Nov. 1886
Crawford, John P., 1, St. Vincent Street, Sunderland ... ... (E) May 1889
Crawford, W. A. F., Tork House, Albert Bridge Road, Battersea, London, S.W. ... ... (E) Nov. 1884
Cross, Wm., 4, Fenham Terrace, Newcastle-on-Tyne ... ... (E) Mar. 1886
Cruddas, W. D., Messrs. Sir W. G. Armstrong, Mitchell, & Co., Elswick, Newcastle-on-Tyne ... ... (E) Dec. 1884
Cumming, William S., c/o Mr. Sutherland, 253, Albert Bridge Road, Mount Pottenger, Belfast... ... ... (S) Oct. 1890
Cummins, W. R., 40, Perth Road, Dundee ... ... (E) Nov. 1884
Curwen, Henry R., c/o Messrs. Palmer's Iron and Shipbuilding Co., Jarrow-on-Tyne ... ... (S) { Graduate, Feb. 1886 / Member, Oct. 1887

D.

Dalrymple, Wm., 8, Aberdare Terrace, South Shields ... ... (E) Dec. 1886
Darling, W. J., Lloyd's Register of Shipping, Leith ... ... (S) April 1887
Darney, John, c/o Messrs. Short Bros., Pallion, Sunderland ... (S) Nov. 1884
Davie, Albert, c/o Messrs. W. Denny & Bros., Leven Shipyard, Dumbarton, N.B. ... ... (E) { Graduate, Feb. 1886 / Member, Oct. 1887
Davison, A. J., Rosedale, Wallwood Road, Leytonstone, Essex ... (E) Oct. 1888
Dawe, Charles, H.M.S. "Katomba," Royal Navy, Sheerness ... (E) Mar. 1890
De-Rusett, Edwin W., Warden House, Percy Park Road, Tynemouth ... ... (S) Nov. 1890
Dick, Francis, 6, Gladstone Street, Sunderland ... ... (E) Nov. 1885
Dickinson, F. T., Park House, Sunderland ... ... (E) { Graduate, May 1885 / Member, Oct. 1886
Dickinson, James, Park House, Sunderland ... ... (E) Nov. 1884
Dickinson, John, Park House, Sunderland ... ... (E) Nov. 1884
Dickinson, W., Park House, Sunderland ... ... (E) Nov. 1884
Dickinson, R. E., c/o Messrs. The Bowling Iron Co., Bradford, Yorkshire ... ... (E) April 1889
Dixon-Brown, L. D., Unthank Hall, Haltwhistle ... ... (S) Nov. 1886
Dixon, Sir Raylton, Cleveland Shipyard, Middlesborough ... (S) Feb. 1888
Dobson, William, Shipbuilder, Walker-on-Tyne ... ... (S) Nov. 1888
Donald, George Gray, 35, Linskill Terrace, North Shields... ... (E) Oct. 1890
Donald, James, 48, St. Luke's Terrace, Pallion, Sunderland ... (S) Nov. 1884
Donovan, J. W., 5, Ash Place, Newcastle Road, Sunderland ... (E) April 1885
Douglas, John F., c/o Messrs. Ramage & Ferguson, Leith ... ... (E) Jan. 1888
Dowsen, Chas., 8, Croft Terrace, Jarrow-on-Tyne ... ... (E) Dec. 1885
Doxford, Charles D., Bainbridge Holme, Tunstall Road, Sunderland (S) Nov. 1884
Doxford, R. P., Pallion Engine Works, Sunderland ... ... (E) Nov. 1884
Doxford, W. Theodore, Pallion Shipyard, Sunderland ... ... (S) Nov. 1884
Drakenberg, J. A., 73, Mybrogatan, Stockholm, Sweden ... ... (E) Feb. 1886
Duckitt, Jno., 4, St. Nicholas' Buildings West, Newcastle-on-Tyne (E) Nov. 1884

ELECTED.

Dudgeon, F. S., 112, Fenchurch Street, London, E.C. ... ... (E) Feb. 1885
Dunlop, William, 31, Hartington Street, Barrow-in-Furness ... (E) Mar. 1888
Dykes, James, 78, Dilston Road, Newcastle-on-Tyne ... ... (E) May 1885
Dykes, John, Lloyd's Register of Shipping, Oriel Chambers, Liverpool ... ... (SUR) Oct. 1889

E.

Eckmann, John, Sunderland Engine Works, South Docks, Sunderland (E) May 1885
Edmiston, Jas. B., Ivy Cottage, Highfield Road, Walton, Liverpool (E) Nov. 1886
Edwards, Guy Williamson, Byethorn, Corbridge-on-Tyne... ... (E) Feb. 1891
Eeles, Robert, Messrs. Eeles & Dryden, 4, Quayside, Newcastle-on-Tyne (E) April 1889
Elliot, Henry, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain... ... ... (E) May 1891
Elliott, Consitt, 4, Salem Hill, Sunderland ... ... (E) May 1885
Ellis, Robert Ellwood, Park Place, Kinghorn, N.B. ... ... (S) Feb. 1891
Eltringham, J., c/o Messrs. J. T. Eltringham & Co., South Shields (E) May 1889
Eltringham, Joseph T., Stone Quay, South Shields ... ... (S & B B) Oct. 1889
English, E. Harold, Messrs. Westgarth, English, & Co., Middlesbro' (E) Feb. 1889
English, Thos. (Lieut.-Col.), Messrs. Palmer's Shipbuilding & Iron Co., Jarrow-on-Tyne ... ... Oct. 1890
Eshelby, William, 1, Lax Terrace, Stockton-on-Tees ... ... (E) Feb. 1888
Evans, Charles, c/o Messrs. Wigham Richardson & Co., Neptune Works, Walker-on-Tyne ... ... (E) Mar. 1891
Evans, Lewis, Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ...(SUR) Dec. 1890
Evans, William, Superintendent Engineer, Caerphilly, near Cardiff (E) Nov. 1889
Evers, G., Lubeck, Germany ... ... (S) Nov. 1884

F.

Fairman, A. E., Helensburgh, Scotland ... ... (N A) Oct. 1886
Farina, A. J., 63, Quayside, Newcastle-on-Tyne ... . (E) Nov. 1884
Faruffini, Capt. M. C., c/o Connitato Pei Designa delle Navi Ministero dilla Marina, Rome, Italy ... ... (N A) Dec. 1888
Feldtmann, H., Bergen, Norway ... ... (E) Jan. 1889
Findlay, John Taylor, 3, Azalea Terrace South, Sunderland ... (S) Feb. 1890
Firth, H. Branson, Thrift House, Ecclesall, Sheffield ... ... (S M) Oct. 1888
Fleming, Charles Edward, 71, Elswick Road, Newcastle-on-Tyne... (E) Nov. 1884
Fletcher, James, 6, Radnor Terrace, Dumbarton Road, Glasgow ... (E) Dec. 1885
Fletcher, Robert, Walker Forge, Walker-on-Tyne ... ... (F M) Dec. 1886
Flohr, Justus, 32, Birkencellies, Stettin, Germany ... ... (E) Oct. 1886
Foley, Nelson, Villa Beatrice, Parco Griffeo, Naples, Italy ... (E) Nov. 1884
Ford, David, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain... ... ... (E) May 1891
Forster, C., 6, East Parade, Newcastle-on-Tyne ... ... (S) Nov. 1888
Forster, William, c/o Messrs. Dixon, Robson, & Co., 2, Collingwood Street, Newcastle-on-Tyne ... ... (E) Mar. 1890
Foster, Henry, Newburn Steel Works, Newburn-on-Tyne ... ... (E) April 1885

ELECTED.

Fothergill, J. R., 1, Bathgate Terrace, West Hartlepool ... ... (E) Mar. 1886
Fownes, Henry, Tyne Forge, Ouseburn, Newcastle-on-Tyne ... (F M) Nov. 1884
Franki, J. P., c/o Messrs. Morts Dry Dock and Engineering Co., Sydney, N.S.W., Australia ... ... (E) Jan. 1886
Furneaux, J. B., Victoria Engine Works, Gateshead-on-Tyne ... (E) Nov. 1885
Furness, John, c/o Messrs. Stephens & Mawson, Bank Chambers, Quayside, Newcastle-on-Tyne ... ... (E) Nov. 1885
Furse, Fred., c/o Messrs. R. & W. Hawthorn, Leslie, & Co., Shipyard, Hebburn-on-Tyne ... ... (S) April 1887

G.

Gannaway, H. G., 108, Bede Burn Road, Jarrow-on-Tyne ... ... (S) Nov. 1884
Garratt, H. A., 3, Haghendon Road, Clifton, Bristol (E) Graduate, Nov. 1884 / Member, Nov. 1886
Garthwaite, John R., c/o Messrs. R. Ropner & Sons, Stockton-on-Tees (S) May 1889
Gayner, Robt. H., Jun., Beech Holm, Sunderland ... (E) Graduate, Mar. 1886 / Member, Oct. 1888
Geddes, Christopher, c/o Messrs. Leeds Forge Co., Leeds ... ... (E) Oct. 1888
Gibson, H., 6, Dundas Street, Monkwearmouth, Sunderland ... (S) Nov. 1884
Gibson, W. H., 37, Tatham Street, Sunderland ... ... (E) Nov. 1884
Glencross, Thos., 11, Ryehill, Newcastle-on-Tyne ... ... (E) Feb. 1885
Glover, Terrot, 6, Azalea Terrace, Sunderland ... ... (E) Mar. 1886
Goddard, George Arthur, Gosforth Station Works, Newcastle-on-Tyne... ... ... (D) Feb. 1890
Gordon, William James, c/o Messrs. Naval Construction and Armaments Co., Barrow-in-Furness ... ... (E) Oct. 1887
Graham, Edwin, Messrs. Osbourne, Graham, & Co., Hylton, Sunderland ... ... (S) Nov. 1884
Graham, Joseph, 13, Whitehall Terrace, Sunderland ... ... Nov. 1884
Graham, T. S., 19, Sea View Terrace, E. Hartlepool ... ... (E) Nov. 1888
Graham, Wm., Ford Lodge, South Hylton, near Sunderland ... (S) Nov. 1884
Gravell, John, Custom House Court, Quayside, Newcastle-on-Tyne (N A SUR) Nov. 1884
Gray, A., c/o Messrs. R. Stephenson & Co., South Street, Newcastle-on-Tyne ... ... (E) Nov. 1888
Gray, George, 13, Harold Street, Sunderland ... ... (E) Feb. 1888
Gray, Harry, 12, Grosvenor Road, Jesmond, Newcastle-on-Tyne ... (E) Dec. 1885
Gray, Matthew, Messrs. W. Gray & Co., West Hartlepool ... ... (S) Oct. 1888
Gray, Sir William, Messrs. W. Gray & Co., West Hartlepool (S & E) Oct. 1888
Green, W. G., c/o Messrs. Palmer's Iron and Shipbuilding Co., Jarrow-on-Tyne ... ... (E) Nov. 1884
Green, William, c/o Messrs. Naval Construction and Armaments Co., Barrow-in-Furness ... ... (E) Oct. 1885
Greig, David William, 31, Westmorland Road, Newcastle-on-Tyne (E) Mar. 1891
Grieves, Robert, 38, Linskill Terrace, North Shields (S) Graduate, Nov. 1884 / Member, Dec. 1886
Grimes, Thomas Benjamin, 45, Eastbourne Grove, South Shields... (E) Mar. 1890
Gulston, A., Clayton Park Lodge, Jesmond, Newcastle-on-Tyne ... (E) Dec. 1888

ELECTED.

H.

Hake, G. A., 29, Rothbury Terrace, Heaton, Newcastle-on-Tyne ...(SUR) Oct. 1888
Hall-Brown, E., 15, Moor Terrace, Hartlepool ... ... (E) Nov. 1888
Hall, Edward, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain ... ... (S) Nov. 1885
Hall, J. Percy, Carville, Laurie Park Road, Sydenham, London, S.E. (E) Oct. 1885
Hall, John W., Abden Shipyard, Kinghorn, N.B. ... ... (S) Oct. 1887
Hamilton, John, 10, Murrell Hill, Carlisle ... ... (E) Nov. 1886
Hamilton, J. H., B.Sc., Engine Works, Sandiacre, near Nottingham (E) Nov. 1888
Hamilton, R. R., c/o Messrs. Maudslay, Sons, & Field, Lambeth, London ... ... (E) Nov. 1884
Hammar, Hugo, c/o Harrison Loring, South Boston, Mass., U.S.A. (S) Nov. 1890
Hansen, F. T., Moss Jernstöberi og Mek Vœrksted, near Christiania, Norway ... ... (E) Nov. 1884
Harding, J. C., 9, Alderson Street, West Hartlepool ... ... (E) Nov. 1884
Hardy, Arthur Francis, c/o Rev. A. Curtis, The Vicarage, White Motley, Essex ... ... (S) Oct. 1887
Harkness, Richard, 8, Grenville Terrace, Grange Road, West Hartlepool ... ... (S SUR) Nov. 1884
Harlow, F., 15, Clayton Park Square, Newcastle-on-Tyne... ... (E) Nov. 1884
Harman, Bruce, 12, Annfield Terrace West, Partick, Glasgow ... (E) Oct. 1886
Harper, J. H., 1, Beaumont Street, North Shields ... ... (E) Jan. 1885
Harrison, Alfred, 13, Nelson Street, Sunderland ... ... (E) Oct. 1889
Harrold, Alexander, 19, Lawton Street, Newcastle-on-Tyne ... (E) Nov. 1884
Harrold, F., 14, Rowell Street, Hartlepool ... ... (E) Nov. 1888
Hartness, J., East Boldon, near Sunderland ... ... (E) Nov. 1884
Harvey, John W. J., 1, Richmond Villa, Chertsey Road, Bristol ... (E) Feb. 1889
Haswell, Robert, 11, Union Street, Hartlepool ... ... (S) Dec. 1888
Havelock, Michael, Commercial Chambers, Side, Newcastle-on-Tyne (E) Dec. 1887
Hawdon, Joseph Y., 16, North View, Heaton, Newcastle-on-Tyne (E) May 1891
Head, Archibald P., Coatham, Redcar, Yorkshire ... (E) {Graduate, Nov. 1884 / Member, Oct. 1887}
Head, Jeremiah, Queen's Square, Middlesborough-on-Tees ... (I M) Oct. 1889
Headlam, Robert, 5, Edward Street, Stockton-on-Tees ... ... (E) Nov. 1886
Heck, John H., Lloyd's Register of Shipping, Newport, Monmouthshire ... ... (S SUR) Nov. 1885
Helyer, A. J., Messrs. J. and G. Thompson & Co., Clydebank, Glasgow ... ... (S) Oct. 1887
Henderson, A. M., Greatham Terrace, West Hartlepool ... ... (E) Nov. 1890
Henderson, George, 54, Westmorland Road, Newcastle-on-Tyne ... (E) Nov. 1884
Henderson, Robert, c/o Messrs. Palmer's Iron and Shipbuilding Co., Jarrow-on-Tyne ... ... (S) Nov. 1884
Hepburn, Alfred, Northumberland Forge, Wallsend-on-Tyne ... (F M) Dec. 1890
Hepple, William, Slipway, North Shields ... ... (E & S) Oct. 1885
Hildrey, A. J., 11, Chester Street, Sunderland ... ... (S) Nov. 1884
Hill, Maxwell, c/o Messrs. Palmer's Iron and Shipbuilding Co., Jarrow-on-Tyne ... ... (S) Nov. 1884

ELECTED.

Hills, Charles Henry, Anglesey Copper Works, Walker-on-Tyne ... (E) Nov. 1889
Hindson, William, Bensham Lodge, Gateshead-on-Tyne ... ... (E) Nov. 1884
Hines, William, H.M.S. "Karrakatta," Royal Navy, Sheerness ... (E) Mar. 1890
Hirst, Richard, 4, Cleveland Road, North Shields ... ... (E SUR) Nov. 1885
Hodge, Rowland F. W., Messrs. C. S. Swan & Hunter, Wallsend-on-Tyne ... ... (S) Dec. 1890
Hogg, James, Upper Coach Lane, North Shields .. .. (B F) Nov. 1889
Hök, Wilhelm, Deptford Shipyard, Sunderland ... ... (S) Oct. 1886
Hole, John W., H.M.S. "Whiting," Royal Navy, Sheerness ... (E) Mar. 1890
Holmes, John H., Portland Road, Newcastle-on-Tyne ... ... (E) Jan. 1888
Homji, A. C. N., 13, Trinity Street, Dhobie, Talao, India ... ... (E) Nov. 1884
Hooper, Ernest, 23, Whitehall Terrace, Sunderland ... ... (E) Nov. 1885
Hunter, George B., Messrs. C. S. Swan, Hunter, & Co., Wallsend-on-Tyne ... ... (S) Nov. 1884
Hunter, J. W., Pendleton House, Stockton Road, Sunderland ... (E) May 1885
Hunter, Summers, c/o Messrs. N.E. Marine Engineering Co., Northumberland Engine Works, Wallsend-on-Tyne ... ... (E) Nov. 1885
Hutchinson, C. W., 6, Park Parade, Westmorland Road, Newcastle-on-Tyne ... ... (E) Nov. 1884

I.

Inglis, John, c/o Messrs. Hawthorn & Co., Leith ... ... (S) April 1887
Inglis, John, Jun., Pointhouse Shipyard, Partick, Glasgow ... (E) Oct. 1886
Irwin, J. H., Sunderland Engine Works, South Docks, Sunderland (E) Nov. 1884
Irwin, Thomas F., 1, St. Alban's Road, Bootle, near Liverpool ... ... (C E & N A) Mar. 1888

J.

Jackson, Vincent, 19, Regent Street, Hartlepool ... ... (S) April 1888
Jackson, A., Surveyor's Office, Board of Trade, North Shields (E SUR) Nov. 1888
Jackson, William S., Messrs. Gourlay Bros. & Co., Camperdown Shipyard, Dundee ... ... (S) April 1891
James, M. C., c/o Messrs. Robert Stephenson & Co., Ld., Engineers and Shipbuilders, Hebburn-on-Tyne ... ... (S) Nov. 1884
Jamieson, John, 25, Azalea Terrace South, Sunderland ... ... (E) Nov. 1885
Jobling, J. C., Blackwall Ironworks, Isle of Dogs, London, E. ... (E) Nov. 1884
Jobling, W. J., Queen Street, Newcastle-on-Tyne ... ... (E & S O) Nov. 1884
John, Edmund, Barry Dock, Cardiff ... ... (E) Dec. 1889
Johnson, Johan, Messrs. Olof, Melin, & Co., Gottenburg, Sweden (S) May 1885
Johnson, T. Allan, 15, Stannington Avenue, Heaton, Newcastle-on-Tyne ... ... (S) Nov. 1884
Johnstone, William, Lloyd's Register of Shipping, 2, White Lion Court, Cornhill, London, E.C. ... ... (SUR) Nov. 1884
Joicey, Jacob G., Forth Banks West Factory, Newcastle-on-Tyne (E) Jan. 1889
Jones, George, c/o Messrs. W. Gray & Co., West Hartlepool ... (S) Oct. 1888
Jorgenson, F., Inspector to Austrian Lloyd's, Constantinople ...(SUR) Nov. 1888

ELECTED.

K.

Keene, H. R., Lloyd's Register of Shipping, Exchange Buildings, Middlesborough ... ... (E) { Graduate, May 1885 / Member, April 1887

Kendall, Stonard O., 17, Eversley Place, Heaton, Newcastle-on-Tyne ... ... (S) Mar. 1891

Keydell, Amandus Edmund, Lloyd's Register of Shipping, Dundee (S) April 1890

Kilvington, W., Northumberland Engine Works, Wallsend-on-Tyne (E) Nov. 1884

King, Donald, Engineering Department, Sociedad Anonima Astilleros del Nervion, Bilbao, Spain ... ... (E) Jan. 1890

Kirkaldy, John, 40, West India Dock Road, London ... ... (E) Nov. 1885

Kirkaldy, William, 16, Derby Street, Sandiford, Glasgow... ... (E) Dec. 1889

Kitching, J. F., Hart Road, West Hartlepool ... ... (E) Nov. 1890

L.

Laidley, R. W., 10, Hunter Street, Sydney, New South Wales ... (E) April 1887

Laing, Arthur, Deptford Shipyard, Sunderland ... ... (S) Nov. 1884

Laing, Jas., Jun., Deptford Yard, Sunderland ... ... (S) Nov. 1884

Laing, John, c/o Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... (E) Nov. 1884

Larkin, James, 2, William Black Street, East Jarrow-on-Tyne ... (E) Nov. 1884

Leckie, Andrew, Cambridge Terrace, West Hartlepool ... ...(SUR) Oct. 1888

Lewis, R. A., Newburn Steel Works, Newburn-on-Tyne ... ... (E) Nov. 1884

Liddell, A. R., 10, Buckt Strasse, Vegesack, Germany ... ... (S) Nov. 1884

Liddell, J., c/o Messrs. Denny & Co.. Engine Works, Dumbarton... (E) Nov. 1884

Lindfors, Hugo, 16, Alexandersgatan, Helsingfors, Finland ... (S) May 1889

Lineham, Wilfrid J., Goldsmiths' Co., Technical Institute, New Cross, London, S.E. ... ... Oct. 1890

List, John, Orchard House Works, Blackwall, London, E. ... (E) April 1891

Littleboy, Chas. Wm., 12, Shaftesbury Street, Stockton-on-Tees ... (S) Oct. 1887

Livingston, Thos., Dunedin House, Jarrow-on-Tyne ... ... (S) Nov. 1884

Livingstone, John, 6, Simonside Terrace, Heaton, Newcastle-on-Tyne (E) Nov. 1884

Lohmeyer, H., 43, Crown Street, Newcastle-on-Tyne ... ... (E) Nov. 1884

Long, A. E., 124, Albert Road, Jarrow-on-Tyne ... ... (S) Nov. 1884

M.

Macarthy, Harry, 9, Dean Street, Newcastle-on-Tyne ... ... (E) Nov. 1888

MacColl, Hector, Messrs MacIlvaine & MacColl, Belfast ... ... (E) Dec. 1890

Maccoy, John, 55, Larkspur Terrace, Newcastle-on-Tyne ... ... (E) Feb. 1886

Mace, W., 253, Albert Road, Jarrow-on-Tyne ... ... (E) Jan. 1886

Macfarlane, Andrew, 26, Thornhill Terrace, Sunderland ... ... (E) Dec. 1890

MacGregor, John, 2, Michaelston Villas, Barrow-in-Furness ... (E) Mar. 1888

MacHaffie, John, 635, Terrace Place, Schenectudy, New York, U.S.A. (E) Dec. 1885

Macmillan, Walter, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain ... ... (E) May 1891

Macoll, D. C., 14, Connaught Terrace, Jarrow-on-Tyne ... ... (S) Nov. 1884

Manuel, G. W., Eildon, Ravensbourne Park, Catford, London ... (E) Dec. 1885

Marlborough, Richard, 11, Brookland Road, Sunderland ... ... (S) Nov. 1884

Marr, James, 6, Ash Place, Sunderland ... ... (S) Nov. 1884

ELECTED

Marshall, F. C., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... (E) Nov. 1884

Marshall, Frank T., 38, Percy Gardens, Tynemouth (E) {Graduate, Jan. 1885 / Member, Oct. 1888

Marshall, R. J., 17, Larkspur Terrace, Newcastle-on-Tyne... ... (E) Mar. 1887

Mastaglio, W. D., 34, Gloucester Street, Newcastle-on-Tyne ... (E) Nov. 1885

Mather, Charles, 44, Warrington Road, Newcastle-on-Tyne ...(SUR) Oct. 1888

Matheson, William, c/o Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn-on-Tyne ... ... (S) Dec. 1889

Matthews, A., The Baths, Blyth ... ... (S) Nov. 1884

Matthews, Jas., c/o Messrs. R. & W. Hawthorn, Leslie, & Co., Forth Banks, Newcastle-on-Tyne ... ... (E) Oct. 1886

Maughan, Wm., 15, Addison Road, Heaton, Newcastle-on-Tyne ... (E) Mar. 1887

Mavor, Alfred E., Victoria Mansions, 32, Victoria Street, London, S.W. ... ... (E E) Feb. 1890

McDougall, Neil, Managing Director British Steam Users' Insurance Society, Ld., 4 & 5, Victoria Buildings, Manchester ... (E) Mar. 1890

McGlashan, Arch., 26, Milton Street, West Hartlepool ... ... (S) Nov. 1885

McIlvenna, J. G., c/o Messrs. The Tyne Pontoon and Dry Docks Co., Wallsend-on-Tyne ... ... (S) Nov. 1884

McIntyre, John, 3, Abbotsford Terrace, Newcastle-on-Tyne ... (S O) Jan. 1885

McKay, Jno., 19, Victoria Avenue, Whitley ... ... (E) Nov. 1884

Menzies, Wm., The Side, Newcastle-on-Tyne ... ... (E) Nov. 1884

Messenger, Thomas, 2, Clarence Lawn, Dover, Kent ... ... (E) Mar. 1887

Metcalf, J. C., 4, Azalea Terrace North, Sunderland ... (SUR) Nov. 1884

Metcalfe, C. S., 5, Tunstall Terrace West, Sunderland ... ... (E) Nov. 1884

Micheli, Pietro, Jun., 5, Via Assarotti, Genoa ... ... (E & N A) Oct. 1888

Middlemass, Thomas, 3, Albert Place, Norton Road, Stockton-on-Tees ... ... (S) Oct. 1889

Milburn, Christopher J., 14, Falmouth Road, Heaton, Newcastle-on-Tyne ... ... (E) Feb. 1888

Millar, Thos., c/o Messrs. Sir W. G. Armstrong, Mitchell, & Co., Walker Shipyard, Walker-on-Tyne ... ... (S) Nov. 1884

Miller, Thomas B., 6, Vernon Terrace, Gateshead-on-Tyne (E) {Graduate, Nov. 1886 / Member, Oct. 1888

Mills, John, c/o Messrs. Greenock Steam Shipping Co., Greenock (E) Feb. 1888

Mills, William, Bridge Crescent, Sunderland ... ... (E) Feb. 1890

Milne, W. J., 2, Westbourne Avenue, Walker-on-Tyne ... ... (S) Nov. 1884

Milton, J. T., Lloyd's Register of Shipping, 2, White Lion Court, Cornhill, London, E.C. ... ... (E SUR) Nov. 1886

Mitchell, Chas., Jesmond Towers, Newcastle-on-Tyne ... ... (S) Nov. 1884

Moffat, D., 36, Falconar Street, Newcastle-on-Tyne ... ... (E) Nov. 1884

Moffitt, George, 42, Stanley Street, Blyth ... ... (S) Oct. 1888

Moffitt, Robert, 13, Grace Terrace, Sunderland ... ... (E) Dec. 1885

Moody, Thomas V., Riding Mill, Northumberland ... ... (E) Dec. 1887

Moor, Frederick, Lindenwood, Park Place, Cardiff... ... ... (E) Oct. 1890

Morgan, W. H., 141, Denmark Street, Heaton, Newcastle-on-Tyne (E) Nov. 1884

ELECTED.

Morison, D. B., 8, Albion Terrace, Hartlepool ... ... (E) Feb. 1885
Mörk, Peter ... ... (E) Nov. 1884
Morrison, Robt., 5, Challoner Terrace, South Shields ... ... (E) Nov. 1886
Morrison, William, Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ... (E SUR) Oct. 1890
Morton, Richard Fraser, 33, Kenilworth Road, Newcastle-on-Tyne (E SUR) Oct. 1890
Mountain, William Chas., Messrs. E. Scott & Co., Close, Newcastle-on-Tyne ... ... (E E) Feb. 1889
Mudd, Thomas, Central Marine Engine Works, West Hartlepool (E) Mar. 1886
Muir, J. M., c/o Messrs. Wigham Richardson & Co., Walker-on-Tyne Nov. 1884
Muir, John, 10, Rium Terrace, Hart Road, West Hartlepool ... (E) Oct. 1888
Muir, Robert, 17, Westmorland Road, Newcastle-on-Tyne ...(SUR) Oct. 1886
Myles, David, Sunderland Engine Works, Sunderland ... ... (E) Nov. 1884

N.

Nastoupil, John, Chief Engineer, Austro-Hungarian Navy, 34, Jesmond Road, Newcastle-on-Tyne ... ... (E) Nov. 1890
Newitt, Leonard, c/o Messrs. Sir W. G. Armstrong, Mitchell, & Co., Elswick Works, Newcastle-on-Tyne ... ... (E E) Dec. 1887
Newton, Richard, Park Square, West Hartlepool ... ... (E) April 1889
Newton, W. A., 29, Sea View Terrace, South Shields (E) { Graduate, May 1885 / Member, Oct. 1886
Nichol, B. G., 49, Leazes Terrace, Newcastle-on-Tyne ... ... (E) Nov. 1884
Nichol, Thos., 50, Ripon Street, Monkwearmouth, Sunderland (SUR) Nov. 1884
Nicholson, James Day, c/o Messrs. Mercantile Dry Dock Co., Jarrow-on-Tyne ... ... (S) Mar. 1891
Nicol, John M., 10, Linskill Place, North Shields ... ... (E) Nov. 1884
Nicolson, G. C., c/o Mr. Shearer, Victoria Jubilee School, Byker, Newcastle-on-Tyne ... ... (E) { Graduate, Oct. 1885 / Member, Oct. 1888
Nicolson, J. T., Engineering Department, University, Cambridge (E) Nov. 1884
Noble, Harry, Northern Machine Tool Works, Forth Road, Newcastle-on-Tyne ... ... (E) Nov. 1888
Norman, W. S., c/o Messrs. Tyne Pontoon and Dry Docks Co., Wallsend-on-Tyne ... ... (E) Nov. 1884
Norton, Harold P., Bureau Steam Engineering, Navy Department, Washington, U.S.A. ... ... Oct. 1890
Noton, F. R., 32, Azalea Terrace, Sunderland ... ... (S) Nov. 1884
Nunes, Enrique E., Engineer, Argentine Navy, 433, Calle Ayacucho, Buenos Ayres ... ... (E) April 1891

O.

O'Neil, J. J., Messrs. R. Stephenson & Co., Shipyard, Hebburn-on-Tyne... ... ... (E) Nov. 1884
Orde, E. L., Orde House, Morpeth, Northumberland ... ... (E) Oct. 1887
Oxley, G., Norman Terrace, Howdon-on-Tyne ... ... Nov. 1884

P.

Pacey, John W., Messrs. Thornwill & Warham, Burton-on-Trent ... (E) Feb. 1888
Parsons, Hon. Charles A., Elvaston Hall, Ryton-on-Tyne ... ... (E E) Dec. 1887

ELECTED.

Parsons, Harry F., 5, Holmside Place, Heaton, Newcastle-on-Tyne (E) Dec. 1890
Patterson, Jas., The Green, Wallsend-on-Tyne ... ... (E) Nov. 1884
Pattison, Jos., c/o J. H. Hallett, Esq., The Docks, Cardiff ... ... (E) Nov. 1884
Paulson, John, The Wm. Cramp & Sons' Ship and Engine Building Co., Philadelphia, U.S.A. ... ... (S) Feb. 1886
Peacock, Alfred Norman, Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ...(SUR) Oct. 1890
Pease, J. F., c/o Messrs. Darlington Forge Co., Darlington... ... (E) Dec. 1888
Penney, R. H., Board of Trade Offices, St. Katharine's Dock House, Tower Hill, London, W.... ... ... (S SUR) Nov. 1884
Pepper, W., The Groves, Yarm Road, Stockton-on-Tees ... ... (E) Nov. 1888
Petersen, John L., 18, Bellerby Terrace, West Hartlepool ... ... (E) Oct. 1888
Petree, James, c/o Messrs. Laird Bros., Birkenhead ... ... (S) Oct. 1885
Philipson, Roland, Tynemouth ... ... (E) Dec. 1884
Phillips, Walter, 108, Fenchurch Street, London, E.C. ... (N A & E) Oct. 1886
Phorson, P., 86, Roker Avenue, Sunderland ... ... (S) Nov. 1884
Piaud, Leon, Bureau Veritas, 8, Place de la Bourse, Paris ... ... (N A) Nov. 1888
Pilcher, F. J., 3, City Buildings, Old Hall Street, Liverpool ... (S) April 1887
Pilling, J., 11, Rosslyn Terrace, Chester Road, Sunderland ... Nov. 1884
Pitt, Frederick William, 26, Wilberforce Terrace, Gateshead-on-Tyne... ... ... (E SUR) Oct. 1890
Plotnicki, E. C., 18, Frank Place, North Shields ... ... (E) Nov. 1886
Poli, Rodolfo, Chioggia, Italy ... ... (N A) Jan. 1890
Potts, Matthew, 86, Glen Terrace, Hebburn-on-Tyne ... ... (S) Dec. 1890
Potts, Robert, 11, Mount Pleasant, Deptford, Sunderland ... ... (S) Oct. 1888
Prest, Stanley Faber, 2, Suffolk Lane, Cannon Street, London ... (E) Mar. 1888
Price, John, 6, Osborne Villas, Jesmond, Newcastle-on-Tyne ... (S) Nov. 1884
Prince, Alfred, Kent Villa, Jarrow-on-Tyne ... ... (E) Nov. 1884
Proud, Anthony, Tyne Docks, South Shields ... ... (E) Dec. 1888
Purdy, A. J., Drawing Office, Navy Yard, Washington, D.C., U.S.A. Nov. 1884
Purves, David, 10, Holland Park Gardens, London, W. ... ...(SUR) Dec. 1885
Putnam, T., Darlington Forge, Darlington ... ...(F M) Nov. 1884
Putnam, William, Darlington Forge, Darlington ... ...(F M) Nov. 1884

Q

Quicke, Herbert John, Summerhill House, Blaydon-on-Tyne ... (E) Feb. 1891

R.

Rae, John, 4, Grey Street, Glasgow, N.B. ... ... (E) April 1886
Ralston, G. C., 5, Watson's Villas, Arthur's Hill, Newcastle-on-Tyne (E) Oct. 1887
Ramage, J. T., The Hawthorns, Bonnington, Edinburgh ... ... (E) April 1887
Ramsay, C. W., Hornsborg, Lgungby, Sweden ... ... Nov. 1884
Rankine, Jno., 16, Ribblesdale Road, Hornsey, London, N. ... (E) Nov. 1884
Rayner, Thomas, 24, Side, Newcastle-on-Tyne ... ... (E) Oct. 1889
Readhead, Jas., Beach View, South Shields ... ... (S) Nov. 1884
Readhead, John, Jun., 18, Thomas Street, South Shields ... ... (E) Mar. 1886
Readhead, R., 28, Sea View Terrace, South Shields ... ... (E) Nov. 1884
Readhead, W. B., South-garth, Westoe, South Shields ... ... (S) Nov. 1886

ELECTED.

Reavell, W., c/o Babcock & Wilcox, 114, Newgate Street, London, E.C. ... ... (E) Graduate, April 1885; Member, Oct. 1887

Reed, Joseph, 25, Side, Newcastle-on-Tyne ... ... (E) Oct. 1889

Reed, J. W., c/o Messrs. Palmer's Shipbuilding and Iron Co., Limited, Engine Works Department, Jarrow-on-Tyne ... (E) Nov. 1884

Rennoldson, C., Messrs. J. P. Rennoldson & Sons, South Shields ... (S) Jan. 1886

Rennoldson, Jos. M., Messrs. J. P. Rennoldson & Sons, South Shields (S) Feb. 1886

Reynolds, Charles H., c/o Messrs. Sir W. G. Armstrong, Mitchell, & Co., Walker-on-Tyne ... ... (S) Mar. 1889

Reynolds, Edward, c/o Messrs. Vickers, Sons, & Co., Sheffield ... (E) Jan. 1888

Reynolds, W. G., 36, Meldon Terrace, South Shields ... ... (E) Oct. 1886

Richardson, Philip Wigham, Neptune Works, Walker-on-Tyne ... (S) Nov. 1890

Richardson, Wigham, Neptune Works, Walker-on-Tyne ... ... (S) Nov. 1884

Richardson, Wm., Hartlepool Engine Works, Hartlepool ... ... (E) Oct. 1888

Richardson, T., Jun., Hartlepool Engine Works, Hartlepool ... (E) April 1888

Rickaby, A. A., Bloomfield Engine Works, Sunderland ... ... (E)

Ridley, J. H., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... (E) Nov. 1884

Rimmington, R. F., 6, Cliff Terrace, Hartlepool ... ... (E) Nov. 1888

Ritson, M., Lloyd's Register of Shipping, 2, White Lion Court, Cornhill, London, E.C. ... ... (E SUR) Nov. 1884

Robinson, B. A., 12, Harold Street, Sunderland ... ... (E) Nov. 1884

Robinson, Frederick F., Adelphi Road, Epsom, Surrey ... ... (E) Dec. 1888

Robinson, William, 7, Choppington Street, Newcastle-on-Tyne ... ... (E) Graduate, May 1885; Member, April 1888

Robson, Arthur, Messrs. J. Blumer & Co., Sunderland ... ... (S) Dec. 1886

Robson, George, 9, Wellington Terrace, South Shields ... ... (E) Oct. 1889

Robson, John H., Engineering Department, Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain ... ... (E) Nov. 1885

Robson, J. M., c/o W. Whyte, B, Lombard Street, Newcastle-on-Tyne (E) Nov. 1884

Robson, M., 19, Zion Terrace, Newcastle Road, Sunderland ... (S) Nov. 1884

Roger, Robert, Stockton-on-Tees ... ... (E) Nov. 1888

Rogers, Herbert M., Lloyd's Register of Shipping, Merchants' Exchange, Cardiff ... ... (SUR) April 1889

Rooke, Charles Bowden, Jun., St. Paul's Road, West Hartlepool ... (E) Nov. 1889

Ropner, Robert, Jun., Preston Hall, Stockton-on-Tees ... ... (S) Feb. 1886

Rowan, Jas., 231, Elliott Street, Glasgow ... ... (E) Nov. 1886

Rowell, G. W., 1, Garden Terrace, Blaydon-on-Tyne ... ... (E) Feb. 1885

Rowell, H., 45, Glen Terrace, Hebburn-on-Tyne ... ... Nov. 1884

Rusden, L., 11, Mistletoe Road, Jesmond, Newcastle-on-Tyne ... (E) Nov. 1884

Rutherford, G., c/o Messrs. Wallsend Slipway Co., Engine Works, Cardiff ... ... (S) Oct. 1886

Rutherford, T. A., 93, Roker Avenue, Sunderland ... ... (S) Nov. 1884

Ryder, C. L., 63, Bute Street, Cardiff ... ... (E) Oct. 1886

S.

Salmon, P. R., St. Bede's Park, Sunderland ... ... (E SUR) Nov. 1884

Sanderson, J., 31, Park Road, Jarrow-on-Tyne ... ... (S) Nov. 1884

ELECTED.

Sandison, M., Elswick Shipyard, Newcastle-on-Tyne ... ... (E) Dec. 1884
Sawyers, John, c/o Messrs. Thos. Wilson, Sons, & Co., Hull ... (E) Oct. 1886
Schaeffer, A. G., 4, Benton Terrace, Newcastle-on-Tyne ... ... (E) Nov. 1884
Scorer, G. S., c/o Messrs. T. & W. Smith, North Shields ... ... (S) Jan. 1885
Scotson, Alf., 80, High Street, Hartlepool East ... ... (S) Feb. 1887
Scotson, Wm., 78, Stafford Street, Wednesbury ... ... (E) Nov. 1884
Scott, Ernest, Close Engine Works, Newcastle-on-Tyne ... ... (E E) Nov. 1884
Scott, George Innes, Three Indian Kings' Court, Quayside, Newcastle-on-Tyne ... ... (E) Oct. 1889
Scott, Joseph R., 9, Queen Street, Newcastle-on-Tyne ... ... (E) Oct. 1887
Scurlock, Thos. Henry ... ... (S) Oct. 1890
Seabury, Edward, 40, West India Road, Limehouse, London, E. ... (E) Mar. 1886
Seaman, C. J., 19, Willington Street, Stockton-on-Tees ... ... (E) Jan. 1889
Seaton, Albert Edward, Messrs. Earle's Shipbuilding Co., Hull ... (E) Jan. 1891
Sells, C. Degrave, 20, Via Almeria, Genoa, Italy ... ... (E) Oct. 1887
Shand, H., 41, Grosvenor Place, West Jesmond, Newcastle-on-Tyne (E) Nov. 1884
Sharp, A. E., 4, Bede Burn Road, Jarrow-on-Tyne ... ... (E) Nov. 1884
Sharp, Mark, 144, Albert Road, Jarrow-on-Tyne ... ... (E) Dec. 1889
Sharpe, H. R., 11, Zingari Terrace, Upton Forest Gate, London ... (E) Nov. 1888
Shaw, Jas., 17, Normanby Terrace, Gateshead-on-Tyne ... ... (E) Jan. 1885
Sheriff, Thomas, c/o Messrs. Robert Mackill & Co., Glasgow ... (E) April 1890
Shevill, W. H., 5, Avenue Terrace, Sunderland ... ... Nov. 1884
Short, J. Y., 49, West Sunniside, Sunderland ... ... (S) Nov. 1884
Short, Jos., 49, West Sunniside, Sunderland ... ... (S) Nov. 1884
Shotten, John W., 13, Meldon Terrace, Heaton, Newcastle-on-Tyne (SUR) Nov. 1886
Simpson, Edward, 2, Neptune Road, Wallsend-on-Tyne ... ... (S) Dec. 1890
Sinclair, R., c/o Messrs. J. Wildridge & Sinclair, Consulting Engineers, Sydney, N.S.W. ... ... (E) Nov. 1884
Sinton, John K., 7, Grasmere Terrace, Gateshead-on-Tyne ... (E) Nov. 1885
Sisson, Wm., Gloucester ... ... (E & N A) Oct 1888
Sisterson, G. R., Locomotive Department, London and South Western Railway, Nine Elms, London, S.W. ... ... (E) Nov. 1884
Sivewright, G. W., 5, Radcliffe Terrace, Hartlepool ... ... (S) Nov. 1886
Smith, C. Hubert, Board of Trade Offices, North Shields ... ...(SUR) May 1889
Smith, C. E., 89, Scarborough Street, West Hartlepool ... ... (E) Nov. 1888
Smith, Eustace, 5, Queen Street, Newcastle-on-Tyne ... ... (S) Nov. 1884
Smith, R. J., Pier Engine Works, South Dock, Sunderland ... (E) Nov. 1884
Smith, Reginald Thomas, St. John's College, Cambridge ... ... (E) April 1888
Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds (E) Oct. 1888
Smith, Thomas Edward, Messrs. John Smith & Sons, Newgate Street, Newcastle-on-Tyne ... ... (E) April 1885
Smith, Wm., 51, Dock Street East, Sunderland ... ... (E) Nov. 1884
Soliani, Nabor, Connitato Pei Designa delle Navi Ministero dilla Marina, Roma, Italy ... ... (S) Jan. 1885
Soulsby, J. C., 4, Bute Crescent, Cardiff ... ... (SUR) Nov. 1886
Sowter, Isaac G., 857, East Congress Street, Detroit, Michigan, U.S.A. ... ... Jan. 1889

ELECTED.

Spear, John, c/o Messrs. T. Wilson & Sons, Hull ... ... (E) Oct. 1887
Spearman, Richard, 118, York Street, Jarrow-on-Tyne ... ... (E) Feb. 1889
Spence, Henry Grant, Messrs. Richardson, Duck, & Co., Stockton-on-Tees ... ... (S) Oct. 1890
Spence, James C., Messrs. Tyne Boiler Works Co., Walker-on-Tyne, or 23, Waverley Terrace, Newcastle-on-Tyne ... ... (E) Dec. 1888
Spencer, J. W., Newburn Steel Works, Newburn-on-Tyne ... (E) Feb. 1885
Stafford, William, Dunston-on-Tyne ... ... (E) Nov. 1885
Stansfield, George R., Aberdare Terrace, South Shields ... ... (E) Mar. 1891
Stephenson, C., 5, West View, Wallsend-on-Tyne ... ... (S) Nov. 1884
Stevenson, Wm., 6, West View, Wallsend-on-Tyne ... ... (E) Nov. 1884
Stewart, H., c/o Messrs. Rollo & Co., 10, Fulton Street, Liverpool (E) Nov. 1888
Stewart, James, 31, Lily Avenue, Jesmond, Newcastle-on-Tyne ... (E) Oct. 1890
Stirling, Andrew, Jun., 3, Greenvale Terrace, Dumbarton ... ... (E) Feb. 1888
Stirzaker, J. C., 16, Grosvenor Place, Newcastle-on-Tyne ... ... (E) Nov. 1884
Stoddart, J. E., Lloyd's Register of Shipping, Dock Office, West Hartlepool ... ... (E SUR) Oct. 1888
Stokoe, Thomas W., 4, Lower Archer Street, West Hartlepool ... (S) Dec. 1885
Stone, Wm., 13, Rosslyn Terrace, Sunderland ... ... Nov. 1884
Stonehouse, Andrew, Jun., c/o General Steam Navigation Co.'s Works, Deptford, London, S.E. ... ... (S) Oct. 1890
Strong, George Aaron, West Percy Street, North Shields ... ... (E) Dec. 1889
Summers, James, 114, Grange Road West, Middlesborough ... (E) Mar. 1889
Surtees, R., c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain ... ... (E) Nov. 1884
Sutton, James, 84, Westmorland Road, Newcastle-on-Tyne ... (S) Jan. 1885
Sutton, Jos., 84, Westmorland Road, Newcastle-on-Tyne (E) {Graduate, Mar. 1886 / Member, Oct. 1886}
Swan, A. S., Grove House, Gosforth, Newcastle-on-Tyne ... ... (S) Nov. 1888
Swan, H. F., Beaufront Castle, Hexham ... ... (S) Nov. 1884
Swan, Thomas, Bank Place, Leslie, Fifeshire ... ... Nov. 1884
Swinburne, T. M., Bewick Road, Gateshead-on-Tyne ... ... (E) Jan. 1885
Swinburne, M. W., 117, Park Road, Newcastle-on-Tyne ... ... (E) Nov. 1884
Swinney, W., 10, Wentworth Terrace, Westoe Lane, South Shields (E) Dec. 1888
Sydserff, Thomas B., Jun., 6, The Polygon, Clifton, Bristol ... (E) Oct. 1888

T.

Tate, Chas. H., 7, Side, Newcastle-on-Tyne ... ... (N A) Nov. 1884
Tatham, Stanley, Montrose, Bromley Park, Bromley, Kent ... (E) Feb. 1887
Taylor, Alexander, Mercantile Chambers, Quayside, Newcastle-on-Tyne ... ... (E) Nov. 1884
Taylor, C. W., South Garth, Westoe, South Shields ... ... (E) April 1885
Thaw, Thomas, 1, Clarence Street, Newcastle-on-Tyne ... ... (E) Dec. 1889
Thompson, C. E., Messrs. J. L. Thompson & Sons, Sunderland ... (S) Nov. 1884
Thompson, Charles, 9, Dean Street, Newcastle-on-Tyne ... ... (E) Feb. 1887
Thompson, Jas., 11, Elmwood Street, Sunderland ... ... (E) Dec. 1886

ELECTED.

Thompson, John, Post Office Chambers, Newcastle-on-Tyne ...(C E) Nov. 1884
Thompson, John, 8, The Brae, Sunderland ... ...(SUR) Dec. 1890
Thompson, J. L., Jun., North Sands Shipyard, Sunderland ... (S) Nov. 1884
Thompson, Robert, North Sands Shipyard, Sunderland ... ... (S) Nov. 1884
Thomson, James, Jun., M.A., c/o Messrs. Sir W. G. Armstrong, Mitchell, & Co., Ordnance Works, Elswick, Newcastle-on-Tyne (E) Nov. 1890
Thorn, W. H., 5, Waterville Terrace, North Shields... ... ... (E) Nov. 1884
Tinkler, Robert Harrison, 44, Blyth Terrace, Gateshead-on-Tyne... (E) April 1891
Tinwell, George, General Gordon Terrace, Sunderland ... ... (E) Jan. 1889
Todd, Surtees, c/o Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn-on-Tyne... ... ... (S) Nov. 1884
Todd, Thomas, 20, Billiter Street, London, E.C. ... ... (E) Nov. 1885
Tone, John M. F., 50, Clayton Park Square, Newcastle-on-Tyne ... ... (E) {Graduate, April 1885 / Member, Oct. 1887
Topham, Henry George, 17, Grafton Road, Whitley, Northumberland ... ... (E) May 1891
Towers, Edward, Jun., 4, Latimer Street, Tynemouth (E) {Graduate, Nov. 1886 / Member, Oct. 1888
Trewent, F. J., 9, Northumberland Terrace, Tynemouth ... ... (S) Dec. 1884
Tritton, S. B., Assistant Locomotive Superintendent, Eastern Bengal State Railway, Kanchrapara, Bengal, India ... (E) Nov. 1884
Tulip, George, 28, Henry Street, Hendon Road, Sunderland ... (E) Dec. 1888
Turner, Henry John, c/o Messrs. R. Stephenson & Co., South Street, Newcastle-on-Tyne ... ... (E) Feb. 1888
Turner, S. J., 74, Tynemouth Road, Heaton, Newcastle-on-Tyne... (E) Mar. 1887
Tweddell, R. H., Meopham Court, Gravesend, London ... ... (E) Jan. 1885
Tweedy, J., Neptune Works, Walker-on-Tyne ... ... (E) Nov. 1884
Twigden, George J., 80, King's Road, Canton, Cardiff ... ... (E) Jan. 1890
Tyzack, George, Dean Street, South Shields ... ... (E) April 1888

U.

Ullstrom, Otto, Messrs. Crompton, Ullstrom, & Crompton, 19, Gracechurch Street, London, E.C. ... ... (S) Nov. 1884
Ulm, John, The Arsenal, Pola, Austria ... ... (E) Nov. 1885

V.

Vianson, N. E., *viâ* Galeazzo Alessi 6 into 1, Genoa, Italy... ... (E) Dec. 1885
Vick, R. W., Messrs. E. Withy & Co., West Hartlepool ... ... (S) Nov. 1888

W.

Wadagaki, Yasuzo, Messrs. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... (E) Jan. 1891
Wailes, E. F., 4, St. Nicholas' Buildings, Newcastle-on-Tyne ... (N A) Nov. 1884
Wailes, T. W., Mount Stuart Dry Docks, Cardiff ... ... (E & S) Oct. 1887
Walker, Archibald, 147, Constitution Street, Leith, N.B. ... ... (E) April 1887
Wallau, J., c/o Messrs. Black, Hawthorn, & Co., Gateshead-on-Tyne (E) Nov. 1884
Walliker, J. F., 6, Lovaine Terrace, North Shields ... ... (E) Nov. 1885

ELECTED.

Wallis, Robert, 75, Heaton Park Road, Heaton, Newcastle-on-Tyne (E) April 1891
Walton, J. G., 26, Fenchurch Street, London, E.C. ... ... (E) Nov. 1884
Warburton, J., 16, Elmwood Street, Sunderland ... ... Nov. 1884
Wardale, Henry, 5, Collingwood Terrace, Gateshead-on-Tyne ... (E) Feb. 1888
Warren, G. R., Lloyd's Register of Shipping, Constantinople ...(SUR) Nov. 1888
Watt, Adam, 14, The Avenue, Sunderland ... ...(SUR) Nov. 1884
Watt, Robert B., c/o Messrs. Raylton Dixon & Co., Middlesborough (S) April 1888
Watts, Philip, Elswick Shipyard, Newcastle-on-Tyne ... ... (S) Nov. 1885
Waugh, G. W., Monkseaton, near Newcastle-on-Tyne ... ... (E) May 1885
Weatherall, J., c/o Messrs. Naval Construction & Armament Co., Barrow-in-Furness ... ... (E) { Graduate, Oct. 1885 / Member, Oct. 1887
Weighton, R. L., M.A., Durham College of Science, Barras Bridge, Newcastle-on-Tyne ... ... (E) Nov. 1884
Weir, John, Engine Department, Messrs. A. Stephens & Sons, Linthouse, Glasgow ... ... (E) Nov. 1884
Weir, William, c/o Messrs. Wigham Richardson & Co., Walker-on-Tyne ... ... (E) Nov. 1889
West, Henry H., 14, Castle Street, Liverpool ... ... (E & N A) Oct. 1886
Westgarth, Tom, Messrs. Westgarth, English, & Co., Middlesborough (E) Oct. 1886
Westmacott, P. G. B., Elswick Engine Works, Newcastle-on-Tyne (E) Nov. 1884
White, C., 13, Mosley Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
White, R. S., Fairfield Works, Govan, Glasgow ... ... (S) Nov. 1884
Whyte, Wm., B, Lombard Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
Widdas, T. D., 5, St. Michael's Road, Aigburth Road, Liverpool (SUR) April 1885
Wiles, John W., 6, West View, Wallsend-on-Tyne ... ... (S) Nov. 1886
Wilkie, J., 9, Croft Avenue, Sunderland ... ... (E) Nov. 1884
Willcox, F. W., 45, Sunniside West, Sunderland ... ... (E) Nov. 1884
Williams, J., 3, Azalea Terrace, Sunderland ... ... (SUR) Nov. 1884
Williams, T. Fitzroy, 64, Linskill Terrace, Tynemouth ... ... (E) Feb. 1890
Wilson, J. T., Spennymoor House, Spennymoor ... (E) { Graduate, April 1885 / Member, Feb. 1886
Wilson, Robert, 19, Victoria Street, Newcastle-on-Tyne ... ... (S) Oct. 1887
Winstanley, P. D., c/o Messrs. Sir W. G. Armstrong, Mitchell, & Co., Elswick Shipyard, Newcastle-on-Tyne ... ... (S) Nov. 1884
Wisnom, Hugh, 50, Fitzroy Avenue, Belfast ... ... (E) Oct. 1890
Withy, H., Middleton Shipyard, West Hartlepool ... ... (S) Nov. 1884
Worsdell, Wilson, North-Eastern Locomotive Works, Gateshead-on-Tyne ... ... (E) Dec. 1888
Wotherspoon R., Board of Trade Offices, West Hartlepool (E SUR) April 1889
Wright, R., 25, Westmorland Road, Newcastle-on-Tyne ... ... Nov. 1884

Y.

Young, J. D., 16, Western Hill, Sunderland ... ... (E) Oct. 1888
Younger, R., Elmire House, Heaton, Newcastle-on-Tyne ... ... (E) Nov. 1884

Z.

Zeeman, J. H., c/o Messrs. The Maas Co., Rotterdam ... ... (S) Oct. 1889
Zeltz, A., Actien Gesellschaft, Weser-in-Bremen ... ... (E) Nov. 1884

ASSOCIATES.

A.

		ELECTED.
Allison, J. S., West Hartlepool	... (S O)	Jan. 1891
Armstrong, S., 14, Victoria Place, Hartlepool	(A)	Nov. 1888

B.

Bacon, William Charles, Chadwick House, West Hartlepool	... (S O)	Dec. 1890
Barklam, George, 167, Dudley Port, Tipton, Staffordshire	...	April 1888
Barraclough, Thomas, West Hartlepool Steam Navigation Co., West Hartlepool	... (S O)	Dec. 1890
Barwick, J. S., Ashbrook Grange, Sunderland	... (S O)	Nov. 1884
Bell, John Henry, North Cliff, Roker, Sunderland ...	(I & S M)	Oct. 1887
Bigge, C. W., Northern Counties Club, Newcastle-on-Tyne ...	(A)	Dec. 1889
Blacklin, Richard James, Dinsdale House, Brougham Terrace, West Hartlepool	... (S O)	Dec. 1890
Branfoot, W. J., Messrs. Tyzack & Branfoot, 18, John Street, Sunderland	... (S O)	Dec. 1887
Briggs, R. S., Moorlands, Sunderland	... (S O)	Dec. 1886
Brunton, John, 3, Prior's Terrace, Tynemouth	... (S O)	Oct. 1886

C.

Carr, Ralph, Thornleigh, Clayton Road, Newcastle-on-Tyne	(A & S O)	Nov. 1886
Cassap, William, 23, Cawley Road, Victoria Park, London, N.E.	...(SUR)	Feb. 1890
Charlton, W. A., St. Nicholas' Buildings, Newcastle-on-Tyne ...	(A)	Mar. 1888
Cohan, Edward Asher, 2, Rumford Place, Liverpool ...	... (S O)	Nov. 1889
Common, Francis James, 5, Elms West, Sunderland ...	(I & S M)	Oct. 1887
Conner, L. R., Exchange, West Hartlepool	... (S O)	Jan. 1891
Corbitt, Michael, Rope Works, The Teams, Gateshead-on-Tyne	... (R M)	Jan. 1890
Coull, John, 43, Stanley Street West, North Shields ...	... (S O)	Oct. 1886
Coverdale, R. H., Messrs. J. Coverdale & Sons, Steamship Owners, West Hartlepool	... (S O)	Nov. 1888
Crosier, Edward James, 9, Lincoln Terrace, Gateshead-on-Tyne	... (A)	Oct. 1889
Crowther, Joseph, Dispensary Lane, Newcastle-on-Tyne ...	... (I M)	Jan. 1889
Culliford, J. H. W., 45, West Sunniside, Sunderland ...	... (S O)	Nov. 1884

D.

Dixon, Robert, Rope Works, The Teams, Gateshead-on-Tyne	... (R M)	Jan. 1890
Dodds, A. P., 13, Dean Street, Newcastle-on-Tyne	... (A)	Jan. 1889
Dodds, Charles Henry, General Manager River Wear Commission, 16, Thornhill Terrace, Sunderland		Oct. 1887
Dodds, John B., 13, Dean Street, Newcastle-on-Tyne		Oct. 1888
Dove, Edward John, 5, St. Nicholas' Buildings, Newcastle-on-Tyne		Oct. 1890

F.

Furness, Christopher, M.P., Victoria Terrace, West Hartlepool	... (S O)	Oct. 1888

G.

Garnett, William, Principal, The Durham College of Science, Newcastle-on-Tyne		Jan. 1889

ELECTED.

Gjemre, Lauritz, Maritime Buildings, King Street, Newcastle-on-Tyne ... ...(S O) Mar. 1886
Greenwell, Thos. G., Sunderland ... ...(S O) Dec. 1886

H.

Haggie, Stevenson, Queen Street, Newcastle-on-Tyne ... ...(R M) Oct. 1890
Harland, George, 1, Westoe Crescent, South Shields ... ... (A) Dec. 1888
Hedley, John H., 10, Esplanade West, Sunderland ... ... (S) Dec. 1886
Heslop, Richard O., Akenside Hill, Newcastle-on-Tyne ... (I & S M) Oct. 1885
Hogg, George J. H., N.E.C. Insurance Association, West Hartlepool (S O) Oct. 1888
Hollis, H. E., 3, St. George's Terrace, Jesmond, Newcastle-on-Tyne (I & S M) Feb. 1885
Hudson, Ralph M., Jun., 8, The Cedars, Sunderland ... ... (S O) Dec. 1886
Hunting, Charles, Jesmond Dene, Newcastle-on-Tyne ... ...(S O) April 1886

J.

Jenkins, William, Consett Hall, Durhamshire ... ... (I & S M) Nov. 1887
Jobson, W. J., c/o Messrs Robert Stephenson & Co., South Street, Newcastle-on-Tyne ... ... (A) May 1889

K.

Kerr, James, 18, Azalea Terrace South, Sunderland ... ... (A) Jan. 1888

L.

Loveridge, W. H., Albert Terrace, West Hartlepool... ... (I & S M) Oct. 1888

M.

Macarthy, George E., 9, Dean Street, Newcastle-on-Tyne ... ...(S O) Oct. 1887
Matthiessen, P. H., 25, Queen Street, Newcastle-on-Tyne ... ...(S O) Oct. 1888
Maughan, William, 13, Mosley Street, Newcastle-on-Tyne... ... (A) Feb. 1887
Mawson, Rowland, Bank Chambers, Quay, Newcastle-on-Tyne ... (S O) Jan. 1889
McNabb, Thos., Cail's Buildings, Quayside, Newcastle-on-Tyne ... (S O) Nov. 1886
Metcalf, Thomas, 18, John Street, Sunderland ... ... (SUR) Jan. 1888
Milburn, J. D., Queen Street, Newcastle-on-Tyne ... ... (S O) Nov. 1884
Miller, T. R., c/o Messrs. Lamplough & Co., 72, Cornhill, London ... ... (A & S O) Nov. 1884
Mudd, John, Sunderland ... ... (I & S M) Nov. 1884
Mulherion, G. F., Croft Villa, Jarrow-on-Tyne ... ... (A) Nov. 1884
Muller, J. C. F., 28, Vieille Route, Antwerp ... ...(SUR) Feb. 1890

N.

Newby, S., Messrs. Thomson & Newby, 13, Bridge Street, Sunderland ... ... (I & S M) Nov. 1884
Nicholson, John, Marine Superintendent, West View House, South Shields ... ... Nov. 1890

O.

O'Hagan, James, St. Nazaire-sur-Loire, France ... ... (A) Oct. 1888
Osbourne, Jas., Hylton, Sunderland ... ... (S) Jan. 1885

ELECTED.

P.

Panton, Hugh, 38, Fawcett Street, Sunderland ... ... (I & S M) Nov. 1887
Patterson, Thos., 6, Argyle Square, Sunderland ... ... (S) Jan. 1885
Pattison, W. J., Messrs. Hunting & Pattison, Exchange Buildings, Quayside, Newcastle-on-Tyne ... ...(S O) April 1886
Perry, Edwin, 23, Side, Newcastle-on-Tyne ... ... (A) Nov. 1885
Phalp, Oliver Almora, 37, Richmond Road, Cardiff ... ...(SUR) Feb. 1889
Pinkney, Thomas, Creswell Villa, Sunderland ... ...(S O) Dec. 1886
Pirrie, Robert Reid, Trinity Chare, Quayside, Newcastle-on-Tyne (S O) Dec. 1889

R.

Ramsay, J. W., 13, Northbrook Road, Lee, Kent ... ... (A) Feb. 1885
Reichwald, A., Lombard Street, Newcastle-on-Tyne ... ... (A) Nov. 1884
Reid, Andrew, Printer, Akenside Hill, Newcastle-on-Tyne ... Nov. 1884
Renwick, G., Messrs. Fisher, Renwick, & Co., Queen Street, Newcastle-on-Tyne ... ...(S O) Nov. 1884
Rickinson, John, 9, Church Street, West Hartlepool ... ...(S O) Nov. 1890
Robson, Frederick, 46, Dean Street, Newcastle-on-Tyne ... ... Oct. 1887
Robson, Thos., 38, North Bridge Street, Sunderland ... ...(S O) Nov. 1884

S.

Scholefield, A., 17, Sandhill, Newcastle-on-Tyne ... ...(S O) Nov. 1884
Scott, W. H., Messrs. Scott Brothers, Dean St., Newcastle-on-Tyne (S O) Nov. 1884
Snowdon, W. F., Salter's Road, Gosforth, Newcastle-on-Tyne ... (E A) Dec. 1886
Squance, J. W., Marine Superintendent, 13, The Avenue, Sunderland April 1888
Steel, George, 77, Church Street, West Hartlepool ... ...(S O) Jan. 1891
Swan, Isaac J., Grove House, Gosforth, Newcastle-on-Tyne ...(S O) Feb. 1888

T.

Taylor, John W., 28, Bridge Street, Sunderland ... ...(S O) Dec. 1886
Temperley, C., 9, Gracechurch Street, London ... ...(S O) Nov. 1885
Thompson, V. T., Baltic Chambers, Sunderland ... ...(S O) Dec. 1886
Towers, Edward, 4, Latimer Street, Tynemouth ... ... (A) Oct. 1888
Tweedy, George, 1, Crosley Square, London, E.C. ... ...(S O) Mar. 1889

V.

Varley, John, 257, High Park Road, Leeds ... ... (I & S M) Mar. 1887

W.

Wait, James, Maritime Buildings, King Street, Newcastle-on-Tyne (S O) Nov. 1884
Wallace, Wm., 27, South Scarborough Street, West Hartlepool ... (A) Oct. 1888
Ward, Joseph, c/o Messrs. Wallsend Slipway Co., Wallsend-on-Tyne (A) Nov. 1886
Warren, Reuben Hynard, Elswick Works, Newcastle-on-Tyne ... (A) Mar. 1890
Watson, Thomas W., Marine Superintendent, Gisburn House, Hartlepool Nov. 1890
Welford, Richard, Gosforth, Newcastle-on-Tyne ... ...(S O) April 1888
Woods, James Jabez, Messrs. Herskind & Woods, West Hartlepool (S O) Oct. 1888

ELECTED.

Y.

Yeoman, F., Messrs. Murrell & Yeoman, West Hartlepool ... (S O) Nov. 1888
Young, William M., Guildhall Chambers, Newcastle-on-Tyne ... (S O) Mar. 1889
Younger, Robert Laurie, Messrs. Greenock Steamship Co., Limited, Greenock ... ... (A) Feb. 1889

GRADUATES.

A.

Adamson, Daniel, c/o Messrs. Joseph Adamson & Co., Hyde ... ... Feb. 1888

B.

Barbour, John, 14, Eslington Terrace, Newcastle-on-Tyne ... ... Nov. 1890
Beale, Harry, Otterburn Villas, Newcastle-on-Tyne ... ... Jan. 1891
Bell, George Arthur, 29, Hawthorn Street, Newcastle-on-Tyne ... ... Oct. 1890
Blackett, Walter, 6, Windsor Crescent, Newcastle-on-Tyne ... ... Nov. 1886
Boyd, William, Jun., North House, Long Benton, Newcastle-on-Tyne ... Nov. 1887
Brodin, Olof, c/o G. E. Petterson, 65, Croft Terrace, Jarrow-on-Tyne ... Mar. 1890
Brown, William Frank, Dawson Square, Tynemouth ... ... Mar. 1891
Bryson, John J., 69, Mount Pleasant, Barrow-in-Furness ... ... Feb. 1889

C.

Clague, James Henry, Birkenhead Iron Works, Birkenhead ... ... April 1891
Cooper, Arthur, 46, Larkspur Terrace, Jesmond, Newcastle-on-Tyne ... Mar. 1891
Cooper, William, 11, Ridley Place, Newcastle-on-Tyne ... ... Nov. 1890
Coull, Alex. B., 43, Stanley Street W., North Shields ... ... Feb. 1887
Cowan, David, 22, Clarendon Terrace, South Shields ... ... Nov. 1890

D.

Davis, Thomas Wilfred, 1, Race Street, Newcastle-on-Tyne ... ... Jan. 1891
Dixon, John R., 79, Osborne Road, Jesmond, Newcastle-on-Tyne ... Oct. 1887
Donkin, Samuel, 5, Dean Terrace, Southwick, Sunderland ... ... Jan. 1888
Doxford, Albert Ernest, B.A., Grinden Hall, near Sunderland ... ... Oct. 1890
Duckitt, J. Brentnall, 9, St. James' Street, Newcastle-on-Tyne ... ... Oct. 1888

E.

Elder, Edward Loudon House, Jarrow-on-Tyne ... ... Nov. 1890

F.

Fairbairn, Jas., Hendon Valley Road, Sunderland ... ... May 1885
Finch, Herbert K., 10, Eversley Place, Heaton, Newcastle-on-Tyne ... Dec. 1888
Foley, Wm. C. le B., 12, Grove Street, Newcastle-on-Tyne ... ... Nov. 1887
Freeman, Alfred J., 2, Regent Terrace, Newcastle-on-Tyne ... ... Dec. 1890

G.

Gaine, Roger L., 17, Park Place E., Sunderland ... ... Dec. 1887
Gibson, Joseph H., 8, Coltart Road, Prince's Park, Liverpool ... ... April 1891
Gibson, W. H., East Farm, Fourstones ... ... Jan. 1890
Gilmour, William Laidlaw, Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne ... ... Mar. 1890

ELECTED.

H.

Hamilton, James, 3, Victoria Square, Newcastle-on-Tyne ... ... Oct. 1887
Henshall, Samuel, 9, Chester Road, Sunderland ... ... May 1885
Hewitt, John, 29, Holly Street, Jarrow-on-Tyne ... ... Nov. 1890
Hilbert De Mattos, James, 42, Russell Square, London .. ..
Holey, J. T., 17, Rainton Street, Millfield, Sunderland ... ... Jan. 1886
Hume, Alfred Ernest, 34, Burdon Terrace, Newcastle-on-Tyne ... ... Oct. 1888

K.

Keen, Harry Bernard, 6, Beauclere Terrace, Sunderland ... ... Dec. 1889
King, John, 24, Gloucester Road, Newcastle-on-Tyne ... ... Dec. 1890

L.

Lander, John, Messrs. Wigham Richardson & Co., Walker-on-Tyne ... Dec. 1889
Lewis, Ernest Edward, 68, Crown Street, Newcastle-on-Tyne ... ... Mar. 1890
Liebert, Richard A. E., 214, Portland Road, Newcastle-on-Tyne ... ... Dec. 1888

M.

Macmillan, Alexander Stuart, c/o Messrs. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... Nov. 1890
McKenna, Francis, 46, Hodgson Street, Willington Quay-on-Tyne ... Dec. 1890
McRobie, Frank, 19, Oxford Street, Newcastle-on-Tyne ... ... Mar. 1889
Metcalf, Thos., Jun., 18, John Street, Sunderland ... ... May 1885
Moffatt, James, 7, Murray's Terrace, Belfast, Ireland ... ... Dec. 1889

N.

Nicholson, C., 9, Sussex Place, Southampton ... ... Nov. 1888
Nicholson, Philip Foster, Sandfield, West Boldon, near Sunderland ... Dec. 1889

O.

Orr, Reginald, 18, Bulwer Street, Shepherd's Bush, London, W. ... ... Mar. 1890
Oxton, Walter, Neptune Works, Walker-on-Tyne ... ... Dec. 1890

P.

Pattison, Matthew Robson, 14, Lambton Street, Sunderland ... ... Mar. 1891
Phillips, George, c/o Messrs. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... Nov. 1890

R.

Reed, Joseph, Springfield, Forest Hall ... ...
Rickaby, Augustine, Bloomfield Engine Works, Monkwearmouth, Sunderland ... ... Nov. 1885
Ritson, Stanley M., 18, St. Bede's Terrace, Sunderland ... ... Nov. 1887
Ross, Wm. Chisholm, 60, St. George's Square, Portsmouth ... ... Dec. 1888
Ross, A. J. C., 2, Hawthorn Terrace, Newcastle-on-Tyne ... ... Oct. 1890
Rowntree, Stanley, 62, Neptune Road, Wallsend-on-Tyne ... ... Jan. 1891
Rutherford, J. T., 40, Wharncliffe Street, Newcastle-on-Tyne ... ... Jan. 1886

S.

Shaw, Thomas, Messrs. Naval Construction & Armament Co., Barrow-in-Furness ... ... Dec. 1885
Skinner, Leslie, 22, Ravensbourne Terrace, South Shields ... ... Dec. 1886

ELECTED.

Smith, Launcelot Eustace, 34, Lovaine Place, Newcastle-on-Tyne ... Oct. 1889
Smithson, Alfred Edward, 1, Dawson Square, Tynemouth ... ... Jan. 1891
Stephens, Henry C. J., 4, Wilberforce Street, Wallsend-on-Tyne... ... Oct. 1890
Stoddart, Swinton, 24, North Milburn Street, Sunderland ... ... May 1885
Strang, T. Rankine, 53, Beverley Terrace, Cullercoats ... ... Nov. 1888
Swan, Charles Sheriton, 29, Percy Gardens, Tynemouth ... ... Nov. 1890

T.

Taylor, M., Hawthorn Road, Gosforth, Newcastle-on-Tyne ... ... Feb. 1889

W.

Wedgewood, Josiah Clement, 7, Sydenham Terrace, Newcastle-on-Tyne ... ... April 1891
Weinberg, Herbert James, Fernbrae, Dundee ... ... April 1891
Westmacott, Alfred, Benwell Hill, Newcastle-on-Tyne ... ... Dec. 1885
Wheeler, O., c/o Messrs. Wigham Richardson & Co., Neptune Works, Walker-on-Tyne ... ... Oct. 1886
White, Ernest T., 5, Catherine Terrace, Gateshead-on-Tyne ... ... May 1889
Wilkinson, Thomas, 14, West View Terrace, Lemington-on-Tyne ... Mar. 1890
Withy, Frederick, 44, Milburn Terrace, Sunderland ... ... Nov. 1890
Wortley, H., c/o Messrs. Schlesinger, Davis, & Co., Wallsend-on-Tyne ... Jan. 1886

Y.

Youll, James A., 11, Sydenham Terrace, Newcastle-on-Tyne ... ... Nov. 1890

MEMOIRS.

THE LATE MR. W. H. BITTLESTON.

Mr. W. H. Bittleston was the son of the Rev. E. Bittleston of South Stainley, near Ripon, and was educated at Bradfield College, near Reading. He was afterwards apprenticed to Messrs. Charles Mitchell & Co., shipbuilders, Low Walker-on-Tyne, with whom he remained for a number of years. After leaving Walker he was appointed assistant manager of the shipbuilding department of the Wallsend Slipway Co., subsequently leaving them for an appointment with Mr. Alexander Taylor, consulting engineer, Newcastle-upon-Tyne. About the year 1883 he left Mr. Taylor for an appointment with the General Steam Navigation Co. of London, with whom he remained till the autumn of 1889, when he decided to start business on his own account as consulting naval architect in the City of London; and the compliment was paid him by his late employers, the General Steam Navigation Co., of still retaining his services for certain classes of work. His untimely death in February, 1891, brought a most promising career to a close. He joined the Institution in the year 1885.

THE LATE MR. RICHARD JOHN NAPIER.

Mr. Richard John Napier served his apprenticeship with the firm of Messrs. James Bertram & Sons, engineers, Leith Walk Foundry, Leith. Subsequently he was engaged as a sea-going engineer, latterly filling the position of chief engineer, and passed with distinction the Board of Trade examination for "extra chief," being the highest honour granted by the Board to marine engineers. During his apprenticeship he was a student of the Leith Science School, where he carried off a number of prizes and honours. He afterwards occupied for some time the post of principal assistant in Lockie's Engineering Academy, Leith, and about the beginning of the year 1887 he left that situation to become engineering surveyor to Lloyd's Register at Newcastle-upon-Tyne. He met his death while in the discharge of his duty in making a survey for the load-line of the S.S. "Caradoc," lying in Howdon Dock, on the River Tyne, by accidentally falling into the hold of that vessel on the 6th of February,

1891. The sad and early death (he was 32 years of age) of one who showed such high attainments, and seemed destined to fill a conspicuous position in the engineering profession, is much to be regretted. He joined the Institution in the year 1888.

THE LATE MR. THOMAS RICHARDSON, M.P.

Mr. Thomas Richardson, M.P., was born on the 6th of June, 1821. He was the eldest son of Mr. Thomas Richardson of Castle Eden. His father, who had been a wood contractor under the Earl of Durham, commenced business later as a timber merchant in Hartlepool, and, in conjunction with Mr. J. Parkin, began shipbuilding also at Hartlepool. In 1838, he also started an engineering establishment at Castle Eden, which was in the year 1847 transferred to Middleton, Hartlepool. It was in these works at Castle Eden that Mr. Thomas Richardson served his apprenticeship; and on the death of his father, in 1850, he succeeded him as sole proprietor of the engine works at Hartlepool. At first these works were solely engaged in the manufacture of locomotive engines, but about thirty years ago they were converted into marine engine works, and under the proprietorship of the late gentleman have been so enlarged and modernised that they are now in a position to turn out from thirty to forty sets of marine engines and boilers in a year. The deceased gentleman, who unsuccessfully contested in 1868, was elected the Parliamentary representative of the Hartlepools in 1874, and again in 1880, 1885, 1886. He died suddenly at his residence, Kirklevington, near Yarm, on the morning of December 29th, 1890. He became a member of the Institution in the year 1888.

During the year the following gentlemen have also been removed by death:—Mr. J. J. Pike, engineer; Mr. John Patterson (Associate), for many years chief clerk in the counting house of the shipbuilding yard of Messrs. Wigham Richardson & Co., Neptune Works, Walker-on-Tyne; Mr. D. W. Iley (Associate), iron merchant, Sunderland.

THE NORTH-EAST COAST INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS.

Constitution and Bye-Laws,

ADOPTED AT A GENERAL MEETING ON THE 4TH MARCH, 1885.

REVISED AT THE CLOSING BUSINESS MEETING HELD ON MAY 4TH, 1887.

RE-REVISED AT THE CLOSING BUSINESS MEETINGS HELD ON MAY 9TH, 1888, MAY 13TH, 1889, AND MAY 11TH, 1891.

CONSTITUTION.

I.—The NAME of the Association is "The North-East Coast Institution of Engineers and Shipbuilders." Name.

II.—The OBJECTS for which the Institution is established are:—The advancement of the science and practice of Engineering and Shipbuilding, and the interchange of ideas and information amongst its members, by means of meetings for the reading and discussion of papers relating thereto, and placing on record its transactions. Objects

III.—The Institution shall consist of Honorary Members, Members, Associates, and Graduates.

IV.—HONORARY MEMBERS shall be such distinguished persons as the Council may elect. Honorary Members.

V.—MEMBERS shall be Principals or Principal Managers engaged in Engineering or Shipbuilding; Civil, Military, or Mining Engineers, or Naval Architects; whose subscription shall be Two Guineas per annum: and other persons engaged in the above professions; whose subscription shall be One Guinea per annum. Members.

VI.—ASSOCIATES shall be such persons as are not strictly Engineers or Shipbuilders, but are connected with or interested in such pursuits, and are deemed by the Council to be eligible for Associate membership. Their subscription shall be One Guinea per annum. Associates

Graduates.

VII.—GRADUATES may be persons under twenty-four years of age, engaged in study or employment to qualify themselves for any of the above professions. Their subscription shall be Half-a-Guinea per annum.

Life Members and Associates.

VIII.—Any MEMBER may become a LIFE MEMBER by a single payment of Twenty Guineas, or any ASSOCIATE may become a LIFE ASSOCIATE by a single payment of Ten Guineas.

Officers.

IX.—The OFFICERS of the Institution shall be elected from and by the Members, and shall consist of one President, the Past-Presidents, nine Vice-Presidents, fifteen Councilmen, and an Honorary Treasurer.

Election of Officers. (See Bye-Law No. II.)

X.—The President and Honorary Treasurer shall be elected annually. Three Vice-Presidents and five Councilmen shall be elected annually. The retiring Vice-Presidents and Councilmen shall be those who have served three years from their last election.

The President shall be eligible for re-election for a second year; should he be re-elected he shall retire at the conclusion of his second year of office, and shall not again be eligible until after an interval of one year.

The retiring Vice-Presidents shall be eligible for re-election. The retiring Councilmen shall not be eligible for re-election to the same office until after an interval of one year, but shall be eligible for election to any other office.

The Honorary Treasurer shall be eligible for re-election annually, or for election to any other office.

Honorary Members' Privileges.

XI.—Honorary Members may attend all the General Meetings, they may read papers, take part in discussions, in voting, in moving and supporting resolutions, in presentation of notices of motion, or in requisitions for Special Meetings, and in the proposition of new members; they shall also receive copies of the Transactions.

Members' Privileges

XII.—Members shall have all the privileges of the Institution as enumerated in the foregoing paragraph, and shall be eligible for office.

Associates' Privileges.

XIII.—Associates shall have all the privileges enumerated in paragraph XI. They shall be eligible for office as Councilmen.

XIV.—Graduates may attend all the General Meetings, they may read papers, take part in discussions, and support resolutions; they shall also receive copies of the Transactions, but shall not sign proposals for new members, vote, nor be eligible for office. Graduates' Privileges.

XV.—The General Meetings of the Institution shall be held during the winter seasons of each year. General Meetings.

NOTE.—When the word Member is initialled with a capital letter it signifies a member under paragraphs IV. and V., but when initialled with a small letter, it signifies a member of any class of the Institution membership.

BYE-LAWS.

Revised at the Closing Business Meetings held on May 4th, 1887, May 13th, 1889, and May 11th, 1891.

MEMBERSHIP.

1.—Every candidate for admission as a Member, Associate, or Graduate shall be proposed and recommended according to the form A in the Appendix, in which form the name, usual residence or the place of business, the qualification for, and proposed class of membership of the candidate shall be distinctly specified. Proposals for Graduates must give the date of, and age, last birthday. Candidates for Admission.

The form shall be signed by a Member or Associate of the Institution, as proposer, and by at least other three Members or Associates as supporters, certifying a personal knowledge of the candidate.

The proposal so made shall be submitted to the Council, when, if it be approved, the Chairman shall sign the approbation, which shall be inserted in the notice calling the next General Meeting, when the candidate shall be balloted for, and shall be accepted if three-fourths of the votes are favourable.

2.—Graduates desirous of becoming Members shall be proposed and recommended according to the Form B in the Appendix. Graduates becoming Members

The proposal so made shall be submitted to the Council, who shall agree to or reject it.

3.—The balloting for membership shall be conducted in the following manner:—Each member shall be supplied by post with Balloting for Members.

a list of the names of the candidates, according to the Form C in the Appendix, and shall strike out the names of such candidates as he desires shall not be elected. These lists may be returned to the Secretary by post, or may be deposited in the ballot-box by the voter in person on entering a meeting at which an election is to take place. The ballot-box will be closed at ten minutes after the advertised time of meeting. The lists shall then be handed over to the Chairman, who shall appoint two Scrutineers to examine them, after which examination the Chairman shall inform the meeting of the result.

Candidates to receive Notice of Election.

4.—Notice of Election as a member shall be sent to the candidate within one week after his election, according to the Form D in the Appendix; but his name shall not be added to the list of Members, Associates, or Graduates of the Institution, until he shall have paid his first annual subscription.

Rejection of Candidates.

5.—In case of rejection of the candidate, no mention thereof shall be made in the minutes, nor shall any notice be given to the unsuccessful candidate.

Subscriptions payable in Advance.

6.—All subscriptions shall be payable in advance, and shall become due on the 1st of June each year. Any Member, Associate, or Graduate, wishing to retire from the Institution shall continue to be liable for his annual subscription until he shall have given formal notice of his retirement to the Secretary, which notice must be given on or before the 31st of August in each year. Application for membership may be made at any time during a Session, and the subscription shall cover the membership up to the 1st of June following.

Receipt of Subscription.

7.—On payment of each subscription the Secretary shall forward to the member an official receipt.

Questions of Privilege.

8.—On question of privilege.—Any person who may be unknown in the meeting shall only be able to claim the privilege in question on proving his membership for the current Session.

Arrears of Subscriptions.

9.—Any member whose subscription is one year in arrear shall be reported to the Council, who shall direct application to be made for it, according to Form E in the Appendix; and in the event of its continuing in arrear until the end of that

Session after such application, the Council shall have the power, after remonstrance by letter, according to the Form F in the Appendix, of declaring that the defaulter has ceased to be a member.

Power of Council to remove Name from List of members.

10.—The Council may refuse to continue to receive the subscriptions of any member who shall have wittingly acted in contravention of the Regulations of the Institution, or who shall, in the opinion of the Council, have been guilty of such conduct as shall have rendered him unfit to continue his membership; and the Council may remove his name from the list of members: and such person shall thereupon cease to be a member of the Institution. Notice of such action of the Council shall be forwarded to the person in question, in accordance with the Form G in the Appendix. The reason for such action of the Council shall not be stated to the person expelled, without the sanction of the Council.

OFFICERS.

Election of Officers.

11.—The Annual Election of Officers shall be conducted in the following manner:—The Council shall meet in March or April, and shall arrange a list of nominations, in accordance with the Form H in the Appendix. Such list shall be presented at the General Meeting immediately preceding the last General Meeting of the Session, and any Member present shall be at liberty to nominate additional Members. The list shall show who remain in office throughout the Council, and who are retiring. It shall nominate new names in the place of the retiring Members, and the number of nominations shall be, at least, two in excess of the number required in each section of the Council. A copy of this ballot list shall be forwarded to each Member and Associate, together with a complete list of Members, to be filled in, in accordance with the instructions printed in the ballot form, and to be returned to the Secretary, to be opened in the presence of the Council, at a Council Meeting which shall be held in April or May, when the scrutiny and counting shall be carried out by the Council. Any Member in voting shall be at liberty to erase any name or names from the

list and substitute the names of any other person or persons eligible for each respective office other than those already placed on the ballot list by the Council and Members of the Institution.

Any voting paper returning either more or less than one President, six Vice-Presidents, one Honorary Treasurer, and fifteen Councilmen, shall be disqualified for the section or sections in which such errors occur, and the votes shall be lost for the said section or sections. The votes given as President, to a Member who is not elected President, shall count to him as a Vice-President; the votes given as Vice-President, or Treasurer, to persons not so elected, shall count to them as Councilmen, unless they have just completed a term of office in such capacity.

The voting list shall not be sent to any Member and Associate whose subscriptions are more than one year in arrear; nor shall any Member be nominated on the list. For this purpose, the Secretary shall prepare, previously to the meeting of Council, a list of those Members whose subscriptions are more than one year in arrears.

Ballot to be declared at May Meeting.

12.—The result of the ballot for Officers shall be declared at the General Meeting, to be held in May, at which meeting general business shall be transacted. At the May General Meeting the newly-elected Officers. after being declared, shall enter into office; and this shall be the last meeting of the Session.

Power of Council to fill up Casual Vacancy.

13.—The Council shall have power to supply any casual vacancy within itself (including any casual vacancy in the office of President), which shall occur between one May Meeting and another; and the Officers so appointed shall retire when the person whose place they fill would have retired. Vacancies not filled up during the year shall be filled at the General Election.

GENERAL MEETINGS.

General Meetings.

14.—The Annual General Meeting shall take place in October, and shall be held in Newcastle. The Ordinary Meetings shall take place in the second week in each following month during the Session, unless otherwise arranged by the Council, and at such hours and places as the Council may determine.

Notice of Meetings.

15.—Seven clear days' notice of every General Meeting, Ordinary or Special, specifying the nature of business to be transacted, shall be given to every member of the Institution.

Special General Meetings.

16.—A Special General Meeting may be convened at any time by the Council, and such meeting shall be convened by the Council whenever such is the declared wish of a General Meeting, or whenever a written requisition, signed by twenty members, specifying the object of the meeting, is left with the Secretary. If, for fourteen days after the delivery of such requisition, a meeting be not convened in accordance therewith, the requisitionists, or any twenty members of the Institution, may convene a Special Meeting in accordance with the requisition. The business discussed at such Special Meetings shall only be that indicated on the notice calling the meeting.

Quorum.

17.—Twenty Members shall constitute a quorum for the purpose of a meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purpose of a Special meeting.

Chairman at Meetings.

18.—The President shall be chairman at every meeting, and in his absence, one of the Past-Presidents or one of the Vice-Presidents; or in the absence of these, a Councilman shall take the chair; or if no Councilman be present and willing to take the chair, the meeting shall elect a Chairman.

Decisions of General Meetings.

19.—The decision of a General Meeting shall be ascertained by a show of hands; or, when five Members or Associates shall demand, or the Chairman may think it desirable, the decision shall be taken by ballot. The manner of counting the votes shall be at the discretion of the Chairman, and an entry in the minutes, signed by the Chairman, shall be deemed sufficient evidence of the decision of a General Meeting. In cases of equality of votes, the Chairman shall have a casting vote; otherwise he shall not vote.

Questions of a Personal Nature in General Meetings.

20.—Questions of a personal nature arising in a General Meeting, shall, if possible, be referred to the Council, otherwise the decision of the meeting shall be taken by ballot on a motion or amendment put to the meeting. The ballot shall be taken by the voters (being Members or Associates) writing "for" and "against" on a slip of paper. The slips shall be folded and

collected, and then counted in the presence of the meeting, and the result announced by the Chairman. Should fewer than twenty votes be given, it shall be understood that the question is shelved, and the votes shall be destroyed without being opened.

Transactions of Business General Meetings.

21.—At every General Meeting of the Institution, the Secretary shall first read the minutes of the preceding meeting, which, on approval, shall be signed by the Chairman; business arising out of these minutes shall then be transacted. The Secretary shall read any notices which may have to be brought before the meeting. Notices of motion may then be given, and other business of the Institution may be attended to; but when a paper is to be read, the foregoing business shall not be extended beyond half-an-hour after the advertised time for commencing the meeting. The paper or papers for the evening shall then be read and discussed.

Dissolving a General Meeting.

22.—If within half-an-hour after the time fixed for holding a General Meeting a quorum is not present, the meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at the meeting so dissolved, may forthwith be done on behalf of the meeting, by the Council; except the reading or discussion of a paper, which shall not proceed in the absence of a quorum.

Adjourning a General Meeting.

23.—Any General Meeting of the Institution may be adjourned by a vote of the Members and Associates present if there be a quorum; if there be not a quorum, the case shall be met by the preceding paragraph.

Introduction of Friends.

24.—Each member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book, together with that of the member introducing him; but if the introducing member be unable to attend the meeting, he may send the name of the visitor to the Secretary. During such portions of any of these meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw. This shall be done if five Members or Associates, or both, present request it.

COUNCIL MEETINGS.

Council Meetings.

25.—The Council shall meet before each General Meeting, or on other occasions when the President shall deem it necessary; being summoned in either case by circular, stating the time of meeting, and the business, so far as is known.

Convening Meeting for Expenditure of Funds.

No business involving expenditure of the funds of the Institution (except by way of payment of current accounts) shall be transacted at any Council Meeting, unless the circular gives six clear days' notice, and states the business.

Discussions of a Personal Character.

All discussions of a personal character in the Council shall be considered and treated as being strictly confidential.

Regulation of Proceedings.

26.—The Council may regulate its own procedure, and delegate any of its powers and discretions to any one or more of its number.

Chairman and Quorum.

The President shall, *ex-officio*, be chairman of all Council Meetings, and in his absence one of the Past-Presidents or one of the Vice-Presidents shall take the chair; or in the absence of these, one of the Councilmen shall be elected to take the chair. Five members of Council, including the Chairman, shall form a quorum.

Sub-Committees.

In the appointment of Sub-Committees, the Council shall determine the number which shall form a quorum in each case, and shall appoint a Chairman. These regulations shall not affect the Finance Committee.

Sub-Committees.

27.—The Council may appoint Committees either from itself, or with the assistance of persons outside, for the purpose of transacting any special business, or of investigating specific objects connected with the work and interests of the Institution.

Sub-Committees.

28.—All Committees or Sub-Committees shall be appointed by the Council, and shall be subject to that body, and shall report to it. The Council shall act upon these reports or recommendations as it may think best.

Invitation to Strangers.

29.—The Council may invite to General Meetings or to Council Meetings any person or persons whose presence and assistance it may desire, and strangers so invited shall be permitted to take part in the proceedings, but not to vote.

Secretary and Treasurer's Duties.

30.—The Secretary, who shall also act as Treasurer, shall be appointed by and act under the direction and control of the Council, and shall be paid such salary as the Council shall determine. He shall attend all meetings, Council and General, and shall take minutes of the proceedings, and enter them in proper books provided for the purpose. He shall write the correspondence of the Institution and Council, read minutes and notices at meetings, report discussions, and, if required by the Council, prepare papers for reading and publication, and read papers and communications at the meetings. He shall receive all payments due to the Institution, and shall bank the cash in hand whenever it amounts to ten pounds. The bank shall be determined by the Council and the banking account shall be in the names indicated in connection with the Finance Committee. He shall keep a cash account book, general and detail, which shall on all occasions be open to inspection by the Finance Committee or by the Council. He shall keep a register of the names of members, so arranged as to distinguish all members whose subscriptions are in arrear. He shall also perform whatever other duties are indicated in the Bye-Laws of the Institution as appertaining to his department; and shall remain in office during the pleasure of the Council. He shall not vote on any resolution.

31.—The following Sub-Committees shall be appointed annually at the first meeting of the Council in each session:—

Finance Committee.

(1) A Finance Committee, to consist of seven persons, viz.: one Past-President or Vice-President, who shall be Chairman; five Councilmen, and the Honorary Treasurer of the Institution; three of whom shall form a quorum. The Treasurer shall be

Payment of Accounts.

empowered to pay all amounts due from the Institution which are under two pounds. All amounts of two pounds and upwards shall be paid by cheque, signed by the Chairman of the Finance Committee (or in his absence, by the President or a Past-President), the Secretary and the Honorary Treasurer. (2) A

Reading and Library Committees.

Reading Committee, to consist of six members of Council. No member who has served on this Committee for three years in succession shall be eligible for re-election until after an interval of one year. (3) A Library Committee, in accordance with Library Bye-Laws, Nos. 1 and 3.

TRANSACTIONS.

Papers to be submitted to Council.

32.—All papers shall be forwarded to the Secretary at least five clear weeks before the proposed date of reading. The Secretary shall submit them for approval to the Council, and on their general approval they shall be handed to the Reading Sub-Committee, three of whom at least, shall read the paper through. The Reading Committee shall be at liberty to strike out any parts which, in their opinion, ought not to be read. They may also make any suggestions to the author as to points which might with advantage be inserted or altered.

Reading Committee.

Printing Transactions.

33.—The papers read, and the discussions on them, or such portions of them as the Council shall select, shall be printed for distribution among the members, each of whom shall receive a copy. These Transactions shall be edited by the Secretary, in accordance with instructions of the Council, who shall have power to omit parts of discussion which may be foreign to the subject, or which it may be deemed undesirable to retain. Each paper shall bear the date on which it was read in General Meeting.

Copy of Papers supplied to members before reading, etc.

34.—Copies of papers to be read during any session will be sent seven days before the date of reading to members who shall have applied to the Secretary for them, in writing, at the commencement of the session. The discussion on a paper shall not be considered closed on the evening on which it is read, but shall be open for renewal at a subsequent meeting, prior to the reading of the paper set down for that date.

Proofs sent to members for Correction.

35.—The Secretary shall send to each speaker as soon as possible after a General Meeting a copy in manuscript of the speaker's own remarks for correction. This copy must be returned to the Secretary within four days. A printed proof will also be sent to each speaker for further revision; this must be returned to the Secretary within three days, otherwise it will be deemed correct, and printed off after receiving verbal corrections.

Liberty to Print Explanatory Notes.

36.—The Council shall be at liberty to print as Transactions, either with the papers and discussions or separately, explanatory notes, etc., communicated after the reading or discussing of a paper. Such communications must be approved by the Reading Committee, and shall bear the date on which they shall have been received by the Secretary.

Institution not responsible for statements.

37.—The Institution shall not be held responsible for the

statements and opinions advanced in any of the papers which may be read, or in the discussions which may take place at the Meetings of the Institution.

Copies of Transactions to be sent to members.

38.—Twenty copies of each paper and discussion shall be presented to the author of the paper, for private use, and one copy shall be sent to each member. When a paper is prepared by two authors, fifteen copies shall be presented to each. Duplicate copies of parts of the Transactions mislaid or lost by members cannot be supplied to them, except as provided for in Bye-Law 41.

Transactions not supplied to Members in Arrears.

39.—The Transactions shall not be supplied free to members whose subscriptions are more than one year in arrear.

Members not to receive Transactions till after First Payment.

40.—Any member elected at any time between the Annual General Meetings shall be entitled to copies of all the Transactions issued during the session to which his first subscription applies; but not until the subscription has been paid.

Transactions the Property of the Institution.

41.—The Transactions of the Institution shall be the exclusive property of the Institution, and shall be published only by the authority of the Council. Additional copies of papers required by authors for their private use can only be procured from the Secretary, at prices fixed by the Council from time to time, and these copies must contain the whole of the discussion following the papers, and be bound in the usual cover, with the addition of the following words:—"By permission of the Council," and "Excerpt Minutes of Proceedings." Duplicate volumes and copies of parts of the Transactions, if in print, can also be obtained from the Secretary, and shall be sold only by him, in such manner and at such prices as the Council shall have fixed.

Rule of Discussion.

42.—During a discussion upon any paper, no person shall be at liberty to speak more than once (except by way of explanation), nor for a longer period than ten minutes.

ACCOUNTS, &c.

Accounts.

43.—The Council shall present the yearly accounts (up to the 31st of May preceding) at the October General Meeting of each year, after they have been audited by a professional Accountant, appointed by the members at the General Meeting in May.

Trustees.

44.—The capital, stock, and funds of this Institution shall be vested in the names of three Trustees, to be elected from time to time as vacancies occur by the members of the Institution at a General Meeting called for that purpose. All mortgages and other securities shall be taken in the names of such Trustees; and on any new appointment the funds shall vest in the newly-appointed Trustee or Trustees jointly with the continuing or remaining Trustee or Trustees.

ALTERATIONS TO CONSTITUTION AND BYE-LAWS.

45.—Alteration in or addition to the Constitution and Bye-Laws may be made only by resolution of the members at the May General Meeting, after notice of the proposed alteration or addition has been announced at the previous General Meeting.

The resolution may be modified by the Council meanwhile, should they so desire; but in this case it shall be read at the May General Meeting in its original form before it is proposed in the amended form.

Such resolutions shall be stated in the notice calling the intervening Council Meeting, and also in the notice calling the May General Meeting.

Vote by Proxy.

Any member unable to be present at the meeting at which such alterations are to be considered, but who is nevertheless desirous of recording his opinion thereon, shall be allowed to vote by proxy, such proxies shall be in Form J in the Appendix, which may be had on application to the Secretary, and may be used by any member present at the meeting on behalf of the absent member, and counted by the Chairman as of equal value with votes given in the manner provided in Bye-Law 19.

THE LIBRARY AND READING ROOM BYE-LAWS.

Committee.

1.—The Library and Reading Room shall be managed by a Committee, called the Library Committee, who shall have charge of all books, papers, specimens, etc., which may belong to the Institution. It shall consist of five members of the Institution, of whom at least two shall be members of Council.

Property. 2.—The books and other property of the Library shall be vested in the Trustees appointed by the Institution.

Appointment of Committee. 3.—The Library Committee shall be appointed annually, at the first meeting of the Council in each session. No member who has served on the Committee for three years in succession shall be eligible for re-election until after an interval of one year. The Chairman shall be elected by the Council.

Librarian. 4.—The Secretary of the Institution shall be Librarian, and shall also act as Secretary to the Library Committee. Three members of the Committee shall form a quorum.

Duties of Committee. 5.—The Library Committee shall be responsible for the binding and purchasing of books, periodicals, papers, etc., and for the expending of all money voted by the Council for its use. It shall appoint an attendant who shall act as Assistant Librarian. It shall make Bye-laws for the management of the Library, subject to the approval of the Council, and present an annual report to the first meeting of the Council held after the annual scrutiny of the books referred to in Bye-law No. 13.

Hours of Opening and Closing. 6.—Except when closed by special order of the Library Committee, or when the Council is sitting, the Library and Reading Room shall be open for consulting, borrowing, or returning books, every week day as follows:—On Monday, Tuesday, Thursday, and Friday, from 10 a.m. to 12 noon, and from 1·30 to 9 p.m.; on Wednesday, from 10 a.m. to 12 noon, and from 1·30 to 5 p.m.; on Saturday, from 10 a.m. to 1 p.m., and from 3 to 9 p.m. The Rooms will be closed on Christmas Day, New Year's Day, and Good Friday, Monday and Tuesday in Easter week and Whit week, and from the first to the second Saturday in March of each year, as mentioned in Bye-law No. 13.

Lending of Books. 7.—Books shall not be lent to any persons except Members, Associates, or Graduates of the Institution, but a person entitled to borrow a book may send a messenger with a signed order for it.

Visitors. 8.—Each member shall be entitled to introduce a friend to the Reading Room, whose name shall be written in the visitors' book, together with that of the member introducing him.

Reference Books. 9.—The books marked with an asterisk in the Catalogue shall be kept only for consultation in the Library, and shall not be lent. Pending the preparation of a Catalogue, the Librarian

shall be instructed by the Committee as to which books shall be withheld from circulation.

Unbound Books

No periodicals, magazines, or pamphlets shall be issued for circulation until after they have been bound and added to the Lending Library.

Register of Books Lent, &c.

10.—The Librarian shall keep a register in which he himself or the attendant shall enter the titles of the books lent, the date of lending, the name of the borrower, and the date of the return of the book to the Library. The borrower of the book or the bearer of his order shall initial the entry of such borrowing, and the Librarian or the attendant shall initial the date of the return of the book.

Number Lent to each Member.

11.—No person shall borrow or have in his possession at one time more than two volumes belonging to the Library.

Return of Book

12.—No member shall retain a book longer than fourteen days, excluding the day of issue. He shall be responsible for the safe return of the book, and if it be damaged or lost he shall make good the cost of such damage or loss.

Yearly Inspection of Books.

13.—All books belonging to the Library shall be called in for inspection and the lending out of books shall be suspended from the first to the second Saturday of March, inclusive, of each year, and members shall be required by an intimation inserted in the notice calling the preceding meeting of the Institution to return all books in their hands before the period mentioned.

Fine.

Members failing to comply with this injunction shall pay a fine of two shillings and sixpence.

14.—Members are requested, when in the Reading Room or Library, to contribute to the general comfort by carefully abstaining from loud talking and noise of any kind. Smoking is not permitted in the Library.

Members in Arrears.

15.—Any member being twelve months in arrears with his subscriptions to the Institution shall not be at liberty to use the Library or Reading Room after the commencement of the first session following.

N.B.—The foregoing Rules may be amended at any time by the Library Committee with the sanction of the Council.

APPENDIX TO BYE-LAWS.

FORM A. (BYE-LAW 1.)

Name (in full)

Profession or Occupation and where Employed

Address

being desirous of admission into the North-East Coast Institution of Engineers and Shipbuilders, we, the undersigned, propose and recommend that he shall become*

thereof. We know him to be†

and eligible for the proposed membership.

* A Member, Associate, or Graduate.

† A Principal, Manager, or Draughtsman, etc See Articles V., VI., and VII. of Constitution.

	FROM PERSONAL KNOWLEDGE.	SECTION OF MEMBERSHIP.
Proposed by		
Supported by Three Members or Associates.		

Dated this day of

(When a Graduate is proposed the age last birthday should be stated.)

FORM B. (BYE-LAW 2.)

A. B. [Christian Name, Surname, Occupation, and Address in full] being at present a of the North-East Coast Institution of Engineers and Shipbuilders, and upwards of twenty-four years of age, and being desirous of becoming of the said Institute, we, the undersigned [Members or Associates], recommend him, from *personal knowledge*, as a person eligible for the proposed Change of membership, because—

(Here specify distinctly the Qualifications of the Candidate according to the spirit of the Rules of the Institution.)

Signed

Three [Members or Associates.]

Dated this day of 18

FORM C. (BYE-LAW 3.)

BALLOTING PAPER FOR MEMBERSHIP.

The Council having considered the recommendations for Membership of the following gentlemen, present them to be balloted for, viz.:—

MEMBER, ASSOCIATE, OR GRADUATE.	OCCUPATION.	ADDRESS.	NOMINATED BY.	SUPPORTED BY THREE MEMBERS OR ASSOCIATES.

Strike out the names of such persons as you desire shall *not* be elected, and forward the list by post to the Secretary, or personally place it in the ballot-box at the Meeting.

FORM D. (BYE-LAW 4.)

SIR,—I am directed to inform you that on the day of you were elected a of the North-East Coast Institution of Engineers and Shipbuilders, but, in conformity with Bye-Law 4, your election cannot be confirmed, nor your name be added to the roll of membership, until you have paid your first annual subscription, the amount of which is £ : : , or, at your option, the Life Composition of £ : : .

Payment may be made to the Treasurer, Mr._____

Address_____

I am, Sir,

Yours faithfully,

Secretary.

Dated 18

N.B.—In case of a Graduate, strike out "*or, at your option, the Life Composition of* £ ‘ ‘ ."

FORM E. (BYE-LAW 9.)

SIR,—I am directed by the Council of the North-East Coast Institution of Engineers and Shipbuilders to draw your attention to Bye-Law 6, and to remind you that the sum of £
of your annual subscriptions remains unpaid, and that you are in consequence in arrear of subscription.

I am also directed to request that you will cause the same to be paid without further delay, otherwise the Council will be under the necessity of exercising their discretion as to using the power vested in them by the Rule above referred to.

I am, Sir,
Yours faithfully,

Secretary.

FORM F. (BYE-LAW 9.)

SIR,—I am directed by the Council of the North-East Coast Institution of Engineers and Shipbuilders to inform you that in consequence of non-payment of your arrears of subscription, and in pursuance of Bye-Law 9, the Council have determined that unless payment of the amount (£) is made previous to the day of next, they will proceed to declare that you have ceased to be a member of the Institution.

But, notwithstanding this declaration, you will remain liable for payment of the arrears due from you.

I am, Sir,
Yours faithfully,

Secretary.

FORM G. (BYE-LAW 10.)

SIR,—I am directed by the Council of the North-East Coast Institution of Engineers and Shipbuilders to inform you that they feel it their duty to advise you to withdraw from the Institution, or otherwise they will be obliged to act in accordance with Bye-Law 9 (or 10, as the case may be.)

I am, Sir,
Yours faithfully,

Secretary.

FORM H. (BYE-LAW 11).

BALLOTING LIST.

PRESIDENT.—ONE NAME only to be returned, or the vote will be lost.

——— President for the current year (eligible for re-election.)*

———
———
——— } New Nominations, from whom to select ONE.

VICE-PRESIDENTS.—NINE NAMES only to be returned (including the six who remain in office), or the vote will be lost.

———
———
———
———
——— } Six Vice-Presidents remaining in office, whose seats are NOT vacant.

———
———
——— } Three Vice-Presidents retiring, eligible for re-election.

———
———
———
———
——— } New Nominations, from whom to select THREE names.

TREASURER.—ONE NAME only to be returned, or the vote will be lost.

——— Treasurer for the current year, eligible for re-election.

———
———
——— } New Nominations, from whom to select ONE.

COUNCILMEN.—FIFTEEN NAMES only to be returned, including the ten who remain in office.

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———
———
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———
———
———
———
———
——— } Ten Councilmen remaining in office. These do not require to be voted for at this election, as their term of service has NOT yet expired.

———
———
———
———
——— } Five Councilmen retiring, and NOT eligible for re-election.

———
———
———
———
———
——— } New Nominations from whom to select FIVE.

* To be crossed out before issue, when the President is not eligible for re-election.

N.B.—(*a*) The names of those who remain in office will be counted in the total number required without being re-written by the voter.

(*b*) Any list having either MORE or LESS than the required number of names voted for in any section will be disqualified for that section.

(*c*) Votes as President for a person who is not elected will count for him as a Vice-President.

(*d*) Votes as Vice-President, or Treasurer, for persons not so elected, will count for them as Councilmen, unless they have just completed a term of office in that capacity.

(*e*) This list, duly filled in, may be returned to the Secretary by post, or handed to him, so as to be on the Council table before the commencement of the scrutiny, which is appointed to take place in the Council Room, at 8 p.m., on 18

(*f*) A copy of this list shall be posted at least Seven Days previous to the Annual Meeting to every Member and Associate, who may erase any name or names from the list and substitute the name or names of any other person or persons eligible for such respective offices, but the number of persons on the list after such erasure or substitution must not exceed the number to be elected to the respective offices.

Secretary.

(FORM J. (BYE-LAW 45.)

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

FORM OF PROXY

FOR VOTES ON ALTERATIONS TO CONSTITUTION OR BYE-LAWS.

I,.....being [an Honorary Member, Member, or Associate] of the above Institution, do hereby appoint Mr..... who is [an Honorary Member, Member, or Associate] of the same Institution, to act as my Proxy, and record my Vote at the General Meeting of the Institution, to be held on the.....day of ....., 18....., and at any adjournment thereof.

Signature.....

Address.....

.....

.....*Secretary.*

NORTH-EAST COAST INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890–91.

PROCEEDINGS.

ANNUAL GENERAL MEETING, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE; ON MONDAY EVENING, OCTOBER 13TH, 1890.

F. C. MARSHALL, ESQ., PAST-PRESIDENT, IN THE CHAIR, *pro tem.*

THE CHAIRMAN said that owing to the absence of Mr. Wigham Richardson from their last meeting he (Mr. Marshall) was unable at that time to have the privilege, as he would then have deemed it, and still deemed it, of installing him publicly into the presidential chair, as had been done on previous occasions. This however had only been a delay in the formality, because their President had, during the interval, fulfilled all the presidential duties, and discharged them, he was sure, to the satisfaction of the Council. It was unnecessary that he should introduce Mr. Richardson to them. He was known very well to every one of them, and to say anything in his presence, more than he had the honour of saying in his absence at last meeting, would be, he thought, unseemly. His position as an engineer, and as a shipbuilder, was world-wide. He (Mr. Marshall) happened to be in the unfortunate position of having to travel about a good deal himself, and wherever the name of "Richardson" was mentioned, in any part of Europe, he could answer for it, it was received with confidence and satisfaction. His attainments as a literary man were known to most of them, while his proficiency and ability as a linguist and man of letters were, he might say, the envy of every one of them. In his installation

as their President, they had the installation of a gentleman, who would do, he was quite sure, honour to the chair which he filled, and not only maintain the Institution in its character and influence and the high position to which it had already attained, but would lead it on to still greater heights of usefulness and of influence. Turning to Mr. Richardson, the Chairman said—Mr. President, in asking you to take the chair to which you have been elected by the unanimous votes of the Institution, I may say that the Institution has not as yet at its disposal a presidential robe to fall as a mantle from the shoulders of one president to those of his successor wherewith to encircle you, nor a chain of office by which it can symbolize the authority with which it invests you; but I can tell you, sir, from my experience it has what is infinitely better; it has perhaps the most earnest, the most intelligent, and the most sincere Council in all that pertains to the usefulness of the Institution, that it is possible to have besides the most praiseworthy assistant in the Secretary, Mr. Duckitt. I have great pleasure in asking you to take the chair and preside over the destinies of the Institution during the ensuing year.

WIGHAM RICHARDSON, ESQ., IN THE CHAIR.

The PRESIDENT, having taken the chair, said, he was extremely obliged for the kindness Mr. Marshall had shown in coming there that evening to introduce him to them, and he begged them to believe that his wish would be to be able to do as well in the office as he (Mr. Marshall) had done in the past two years. He would not say more at present, but call upon the Secretary to read the minutes of the Closing Meeting of last session.

The SECRETARY read the minutes of the preceding Closing Meeting held in Newcastle on May 12th, which were approved by the members present and signed by the President. The ballot for new members having been taken, the President appointed Messrs. J. R. Fothergill and H. Macoll to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Craig, John C., Forge Inspector to Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne.

Cumming, William S., Chief Ship Draughtsman to Messrs. Naval Construction and Armaments Co., Barrow-in-Furness.

Donald, George Gray, Engineer. 35. Linskill Terrace, North Shields.

English, Thos. (Lieut.-Col.), Ordnance Works Manager, Messrs. Palmers' Shipbuilding and Iron Co., Jarrow-on-Tyne.

Lineham, Wilfrid J., Professor of Engineering and Mechanical Science, Goldsmiths' Co., Technical Institute, New Cross, London, S.E.

Moor, Frederick, Engineer, Lindenwood Park Place, Cardiff.

Morrison, William, E. Surveyor to Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne.

Morton, Richard Fraser, E. Surveyor to Lloyd's Register of Shipping. 3, St. Nicholas' Buildings, Newcastle-on-Tyne.

Nicol, George, Marine Superintendent to Messrs. Adam Bros. & Co., Newcastle-on-Tyne.

Norton, Harold P., Engineer Corps, U.S. Navy, Bureau Steam Engineering, Navy Department, Washington, U.S. of America.

Peacock, Alfred Norman, Surveyor to Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne.

Pitt, Frederick William, E. Surveyor to Lloyd's Register of Shipping, 3, St. Nicholas' Buildings, Newcastle-on-Tyne.

Scurlock, Thos. Henry, Ship Draughtsman, 237. Albert Road, Jarrow-on-Tyne.

Spence, Henry Grant, Shipbuilder, Messrs. Richardson, Duck, & Co., Stockton-on-Tees.

Stewart, James, Supt. Engineer to Messrs. Adam Brothers & Co., Newcastle-on-Tyne.

Stonehouse, Andrew, Jun., Ship Draughtsman, Messrs. J. Scott & Co., Kinghorn, N.B.

Wisnom, Hugh, Assist. Supt. Engineer, Messrs. Ulster S.S. Co., Belfast, 50, Fitzroy Avenue, Belfast.

ASSOCIATES.

Dove, Edward John, Cement Manufacturer, 5. St. Nicholas' Buildings, Newcastle-on-Tyne.

Haggie, Stevenson, Rope Manufacturer, Queen Street. Newcastle-on-Tyne.

GRADUATES.

Bell, George Arthur, E. Apprentice, 29, Hawthorn Street, Newcastle-on-Tyne.

Doxford, Albert Ernest, B.A., Engineer, Grinden Hall, near Sunderland.

Stephens, Henry C. J., E. Apprentice, 4, Wilberforce Street, Wallsend-on-Tyne.

The Council's Report and Treasurer's Statement for the sixth session was read by the Secretary, and submitted to the meeting for adoption.

COUNCIL REPORT.

(SIXTH SESSION.)

THE Council in presenting its sixth annual report has pleasure in stating that the finances of the Institution are in a satisfactory condition.

During the session the following papers have been read and discussed:—

1.—"Notes on the Surveying and Classification of Shipping." By Mr. G. E. Macarthy.
2.—"The Strength of Boilers." By Mr. James C. Spence.
3.—"The Construction of Marine Boilers with a view to the use of Higher Pressures." By Mr. C. B. Casebourne.
4.—"High Speed Engines for Cargo Boats." By Mr. E. Hall-Brown.
5.—"Boiler Furnaces." By Messrs. W. Kilvington and A. Taylor.
6.—"The Normal Indicated Horse-Power of Marine Engines and Boilers." By Mr. R. L. Weighton, M.A.
7.—"The Structural Strength of Cargo Steamers of different Types." By Mr. G. Bergström.
8.—"The Weight of Machinery in the Mercantile Marine." By Mr. William Boyd.

Early in the session the President, Mr. F. C. Marshall, convened a meeting of the Graduate Members of the Institution, the result of which was that a Graduate section for the reading and discussing of papers among themselves was inaugurated, a code of bye-laws drawn up, and Mr. Frank T. Marshall was appointed President, and Mr. H. R. Curwen Hon. Secretary for the year. A very instructive address was delivered by Mr. Frank T. Marshall at the first meeting, and at subsequent meetings the following papers were read and discussed:—

"Crank Shafts for Marine Engines." By Mr. O. Wheeler.
"Steam Engine Trials." By Mr. B. Bramwell.

Visits were also paid to several of the most interesting works in the district. The Council hopes that all the younger members of the Institution will take an active interest in this section, and that the work thus begun will prove both useful, instructive, and of mutual benefit to all.

During the past year the following additions have been made to the list of members:—56 Ordinary Members, 9 Associates, and 11 Graduates. The Institution regrets having to record the loss by death of the follow-

ing members:—Mr. William Clarke, Mr. Alexander Hepburn, Mr. D. Martens, Mr. William Robinson, Mr. Thomas Wilson, and Mr. George Roberts (Associate). It has also lost by resignations and other causes 31 Members, 1 Associate, and 4 Graduates.

Several matters of importance have engaged the attention of the Council. Of these the following, which are still under consideration, may be mentioned:—The representation of Engineers and Shipbuilders on Lloyd's Committee; the question of this Institution associating with the Literary and Philosophical Society; and the election of a Professor to the Chair of Naval Architecture and Engineering in the Durham College of Physical Science.

The thanks of the Institution are due to those firms and gentlemen who have kindly contributed to the following Funds, a list of whom is appended to the Financial Statement attached to this Report:—The Library Furnishing Fund; the Gold Medals' Fund; and the Graduates' Award Fund. The sums contributed to the Gold Medals' and Graduates' Award Funds, together with the amount received from the Life Members and Life Associates, in all £605, have been handed over to the Trustees of the Institution for investment.

FINANCIAL STATEMENT.

NORTH-EAST COAST INSTITUTION OF

STATEMENT OF RECEIPTS AND PAYMENTS

Receipts.

				£	s.	d.	£	s.	d.
To Balance from last Account—									
At Bankers				315	8	2			
In hand				1	3	4			
							316	11	6
„ Subscriptions received for Session 1889–90—									
197 Members at £2 2s.	£413	14	0						
89 Associates „ £1 1s.	93	9	0						
368 Members „ £1 1s.	386	8	0						
49 Graduates „ 10s. 6d.	25	14	6						
703				919	5	6			
For Sessions 1886 to 1889 (arrears)—									
5 Members at £2 2s.	£10	10	0						
21 Members „ £1 1s.	22	1	0						
4 Members „ 10s. 6d.	2	2	0						
1 Associate „ £1 1s.	1	1	0						
1 Graduate „ 10s. 6d.	0	10	6						
				36	4	6			
32							955	10	0
„ Transactions Sold this Session from Stock				37	12	9			
„ Copies of Members' Papers supplied				34	13	2			
„ „ „ for 1885–6				6	15	0			
							79	0	11
„ Donations as per List—									
Library Fund				33	12	0			
Gold Medals' Fund...				274	0	0			
Graduates' Award Fund				215	15	0			
							523	7	0
							£1,874	9	5

ENGINEERS AND SHIPBUILDERS.

FOR SESSION ENDING 31ST MAY, 1890.

Payments.

	£	s.	d.	£	s.	d.
By Transactions and Papers—						
Lithographing	124	1	6			
Printing and Binding	171	11	6			
				295	13	0
„ Stationery and Circulars	45	17	0			
„ Reporting	23	9	6			
„ Advertising	2	7	0			
„ Rents—						
Offices	65	4	0			
Lecture Rooms	7	12	2			
„ Rates, Gas, and Insurance	12	16	3			
„ Fees to Hall Keepers	1	1	0			
„ Salaries—						
Secretary's Salary	120	0	0			
„ Commission	47	15	6			
Assistant Librarian	25	0	0			
„ Postage Stamps, Post Cards, and Parcels	82	10	8			
„ Secretary's Expenses	5	7	10			
„ Office Expenses, Coals, Cleaning, etc.	18	7	3			
„ Hanging Drawings	0	6	6			
„ Rent for Measured Mile Posts	3	3	0			
„ Repairs to „ „	11	18	0			
„ Auditor's Fee	3	3	0			
				475	18	8
„ Library Fund—						
Furniture	6	6	0			
Bookbinding	14	6	6			
				20	12	6
„ Donation to Literary and Philosophical Society				21	0	0
„ Tyne Improvement Commissioners—Investment of Funds, viz.:—						
Gold Medals' Fund...	274	0	0			
Graduates' Award Fund	215	15	0			
Payments by Life Members and Associates	115	5	0			
				605	0	0
„ Balance—						
At Bankers	456	3	10			
In hand	0	1	5			
				456	5	3
				£1,874	9	5

THE BALANCE SHEET.—31ST MAY, 1890.

Liabilities.	£	s.	d.
Capital	1,473	2	7
	£1,473	2	7

Assets.				£	s.	d.	£	s.	d.
Subscriptions in Arrear—									
Session 1887-8				3	3	0			
„ 1888-9				16	5	6			
„ 1889-90				67	4	0			
							86	12	6
Stock of Transactions, valued at							133	18	10
Office and Library Furniture, Safe, etc., as at 31st May, 1889...	£150	0	0						
Less—Depreciation	15	0	0						
				135	0	0			
Additions this Session				6	6	0			
							141	6	0
Books in Library, valued at							50	0	0
River Tyne Commissioners—Investment of the following Funds:—									
Gold Medals' Fund				274	0	0			
Graduates' Award Fund				215	15	0			
Payments by Life Members and Associates				115	5	0			
							605	0	0
Cash—At Bankers				456	3	10			
In hand				0	1	5			
							456	5	3
							£1,473	2	7

Newcastle-upon-Tyne, 27th September, 1890.

Audited and certified,
R. W. SISSON, F.C.A.

DONATIONS.

LIBRARY FURNISHING FUND.

	£	s.	d.
Messrs. W. Doxford & Sons, Sunderland	10	0	0
F. C. Marshall, Esq., Tynemouth	10	0	0
W. H. White, Esq., London	10	0	0
Messrs. W. Gray & Co., West Hartlepool	5	5	0
H. F. Swan, Esq., Newcastle-on-Tyne	5	5	0
Right Hon. Earl Ravensworth, Newcastle-on-Tyne	5	0	0
Right Hon. Lord Armstrong, Newcastle-on-Tyne	5	0	0
Messrs. Thos. Richardson & Sons, West Hartlepool	4	4	0
Messrs. E. Withy & Co., West Hartlepool	4	4	0
Messrs. Herskind & Woods, West Hartlepool	3	3	0
Sir B. C. Browne, Newcastle-on-Tyne	2	2	0
W. A. F. Crawford, Esq., Newcastle-on-Tyne	2	2	0
W. Cross, Esq., Newcastle-on-Tyne	2	2	0
Sir Raylton Dixon, Middlesbrough	2	2	0
Edward Eccles, Esq., Newcastle-on-Tyne	2	2	0
Christopher Furness, Esq., West Hartlepool	2	2	0
J. Percy Hall, Esq., London	2	2	0
G. B. Hunter, Esq., Newcastle-on-Tyne	2	2	0
H. Macoll, Esq., Sunderland	2	2	0
James Readhead, Esq., South Shields	2	2	0
Robert Readhead, Esq., South Shields	2	2	0
Seebohm & Dieckstahl, per H. E. Hollis, Esq.	2	2	0
D. Andrew, Esq.	1	1	0
S. P. Austin, Esq., Sunderland	1	1	0
W. Boyd, Esq., Newcastle-on-Tyne	1	1	0
Messrs. Brigham & Cowan, South Shields	1	1	0
J. Bulmer, Esq., Newcastle-on-Tyne...	1	1	0
F. Cannell, Esq., Lisbon	1	1	0
Ralph Carr, Esq., Newcastle-on-Tyne	1	1	0
H. Chapman, Esq., Newcastle-on-Tyne	1	1	0
H. Charlton, Esq., Gateshead-on-Tyne	1	1	0
Messrs. J. G. Charlton & Co., Newcastle-on-Tyne	1	1	0
C. J. D. Christie, Esq., Newcastle-on-Tyne	1	1	0
Nelson Foley, Esq., Naples	1	1	0
J. R. Fothergill, Esq., West Hartlepool	1	1	0
J. Gravell, Esq., Newcastle-on-Tyne...	1	1	0
A. Gray, Esq., Newcastle-on-Tyne	1	1	0
A. Harrold, Esq., Newcastle-on-Tyne	1	1	0
W. Hepple, Esq., North Shields	1	1	0
W. Hindson, Esq., Gateshead-on-Tyne	1	1	0
Carried forward	£106	3	0

	£	s.	d.
Brought forward	106	3	0
Messrs. Hunting & Pattison, Newcastle-on-Tyne	1	1	0
G. Jones, Esq., West Hartlepool	1	1	0
W. Kilvington, Esq., Newcastle-on-Tyne	1	1	0
A. Leckie, Esq., West Hartlepool	1	1	0
C. W. Littleboy, Esq., Stockton-on-Tees	1	1	0
G. E. Macarthy, Esq., Newcastle-on-Tyne	1	1	0
A. Matthews, Esq., Blyth	1	1	0
J. Matthews, Esq., Newcastle-on-Tyne	1	1	0
W. Maughan, Esq., Newcastle-on-Tyne	1	1	0
W. Menzies, Esq., Newcastle-on-Tyne	1	1	0
T. Metcalf, Esq., Sunderland	1	1	0
J. T. Milton, Esq., London	1	1	0
C. Mitchell, Esq., Newcastle-on-Tyne	1	1	0
D. B. Morison, Esq., West Hartlepool	1	1	0
T. Mudd, Esq., West Hartlepool	1	1	0
G. F. Mulherion, Esq., Jarrow-on-Tyne	1	1	0
R. Muir, Esq., Newcastle-on-Tyne	1	1	0
Hon. C. Parsons, Ryton-on-Tyne	1	1	0
J. Petersen, Esq., West Hartlepool	1	1	0
E. Perry, Esq., Newcastle-on-Tyne	1	1	0
W. Phillips, Esq., London	1	1	0
R. Philipson, Esq., Tynemouth	1	1	0
J. Price, Esq., Newcastle-on-Tyne	1	1	0
E. Reynolds, Esq., Sheffield	1	1	0
F. Robson, Esq., Newcastle-on-Tyne	1	1	0
W. M. Roche, Esq., Sunderland	1	1	0
Messrs. R. Roger & Co., Stockton-on-Tees	1	1	0
J. A. Rowe, Esq., London	1	1	0
James Rowan, Esq., Glasgow	1	1	0
A. G. Schaeffer, Esq., Newcastle-on-Tyne	1	1	0
A. Scholefield, Esq., Newcastle-on-Tyne	1	1	0
J. K. Sinton, Esq., Newcastle-on-Tyne	1	1	0
G. W. Sivewright, Esq., West Hartlepool	1	1	0
John Spear, Esq., Hull	1	1	0
J. C. Stirzaker, Esq., Newcastle-on-Tyne	1	1	0
J. E. Stoddart, Esq., West Hartlepool	1	1	0
J. Summers, Esq., Newcastle-on-Tyne	1	1	0
M. W. Swinburne, Esq., Newcastle-on-Tyne	1	1	0
A. Taylor, Esq., Newcastle-on-Tyne	1	1	0
J. Temperley, Esq., London	1	1	0
R. Thompson, Esq., Sunderland	1	1	0
G. Tinwell, Esq., Sunderland	1	1	0
J. Tweedy, Esq., Newcastle-on-Tyne	1	1	0
Carried forward	£151	6	0

	£	s.	d.
Brought forward	151	6	0
G. Tyzack, Esq., South Shields	1	1	0
J. Varley, Esq., Leeds	1	1	0
T. W. Wailes, Esq., Cardiff	1	1	0
J. Wallau, Esq., Gateshead-on-Tyne...	1	1	0
J. F. Walliker, Esq., Newcastle-on-Tyne	1	1	0
J. G. Walton, Esq., London	1	1	0
Messrs. Warley, Pickering. & Co., West Hartlepool	1	1	0
H. B. Watson, Esq., Newcastle-on-Tyne	1	1	0
P. Watts, Esq., Newcastle-on-Tyne	1	1	0
R. L. Weighton, Esq., Newcastle-on-Tyne	1	1	0
C. White, Esq., Newcastle-on-Tyne	1	1	0
W. Whyte, Esq., Newcastle-on-Tyne	1	1	0
F. Yeoman, Esq., West Hartlepool	1	1	0
R. Younger, Esq., Newcastle-on-Tyne	1	1	0
R. Fletcher, Esq., Newcastle-on-Tyne	1	0	0
A. Reichwald, Esq., Newcastle-on-Tyne	1	0	0
D. Stephens, Esq., Newcastle-on-Tyne	1	0	0
R. Welford, Esq., Newcastle-on-Tyne	1	0	0
M. Havelock, Esq., Newcastle-on-Tyne	0	10	6
Sundries as per Receipt and Payment Account, May, 1889	3	8	6
	£173	19	0

GOLD MEDALS' FUND.

	£	s.	d.
C. Furness, Esq., West Hartlepool	137	0	0
H. Withy, Esq., and R. W. Vick, Esq., West Hartlepool	137	0	0
	£274	0	0

GRADUATES' AWARD FUND.

	£	s.	d.
Messrs. Palmers' Iron and Shipbuilding Co., Jarrow-on-Tyne	30	0	0
Messrs. Hawthorn, Leslie, & Co., Newcastle-on-Tyne	25	0	0
Messrs. W. Doxford & Sons, Sunderland	20	0	0
C. Mitchell, Esq., Newcastle-on-Tyne	20	0	0
Messrs. Wigham Richardson & Co., Newcastle-on-Tyne	20	0	0
John Readhead, Esq., South Shields	20	0	0
Messrs. C. S. Swan & Hunter, Newcastle-on-Tyne...	20	0	0
Messrs. J. L. Thompson & Sons, Sunderland	20	0	0
W. J. Bone, Esq., North Shields	10	10	0
W. Boyd, Esq , Newcastle-on-Tyne	10	0	0
Messrs. W. Gray & Co., West Hartlepool	10	0	0
S. P. Austin, Esq., Sunderland	5	5	0
H. F. Swan, Esq., Newcastle-on-Tyne	5	0	0
	£215	15	0

The PRESIDENT said, it was usual for the adoption of this report to be moved from the chair. He was sure they would all consider it an extremely satisfactory one, with perhaps the exception of the first paragraph on page 6, giving the names of those who had gone before, and they must all very much regret the losses which they had sustained. The first name that came on the list, Mr. William Clarke, was one of his oldest engineering friends, and he (the President) always looked upon him as one of the very first men of the district. He never met anyone equal to him for the organisation of works, and he considered his decease a very great loss to them as engineers and business men, and to himself as that of a very dear friend. As regarded the Graduate section, which formed a part of their Institution, he was sure they all wished very great success to the first meeting of the session which had to take place on October 22nd. There would then be an election of President, an Honorary Secretary, and Committee, and he believed several members of the Council intended taking part in the meeting. He very much wished that this section of their Institution might be extremely successful. They would remember that the sum of £215 had been invested, the interest of which would be set apart for prizes for the best papers read by the Graduates. As regarded the finances, they would be pleased to hear that the Council had set aside a sum, not exceeding £60, for the purchase of books, and he had no doubt that before long the rooms of the Institution would contain a library of reference, which would be extremely useful and second to few, if any, in this part of the country, or in England. He begged to move the adoption of the annual report and financial statement.

The motion was carried *nem. con.*

SUB-COMMITTEE OF LLOYD'S REGISTER.

Mr. ARTHUR LAING had great pleasure in moving the confirmation of the election by the Council of the following four gentlemen to represent, for a term of four years, the shipbuilders and engineers of the North-East Coast district on the new Sub-Committee of Lloyd's Register of Shipping, viz.:—William Boyd, Esq., Newcastle-on-Tyne; Francis Carr Marshall, Esq., Tynemouth; Robert Thompson, Esq. (Messrs. J. L. Thompson & Sons), Sunderland; and Henry Withy, Esq., West Hartlepool. He felt that they had in these gentlemen those who were fully qualified to represent not only the North-East Coast Institution of Engineers and Shipbuilders, but the shipbuilders and engineers of the whole of the North-East Coast. The nominations commended themselves to him in this way, that they had two representatives for the Tyne, one for the Wear, and one for

West Hartlepool, and that while the two for the Tyne were engineers, those for Sunderland and West Hartlepool were shipbuilders. He was sure they would do this Institution every credit.

Mr. GEORGE B. HUNTER seconded the confirmation. He thought there would be no question as to their being very well represented by the gentlemen named. He heartily concurred in their election.

The motion was adopted.

INVESTMENT OF FUNDS.

Mr. ROBT. THOMPSON (Sunderland) submitted the following resolution:—

"The Trustees appointed by the Institution having invested the sums of £274 and £331, which they hold in trust for this Institution, upon the security of the River Tyne Commissioners, and this investment not falling within the terms of the instruments creating the Trust, in order to relieve the said Trustees from any liability in consequence of their having stepped outside the terms of the Trust, the members of this Institution are hereby called upon to consider, and if agreed upon, to pass the following Resolution:—

Resolved that this General Meeting of the North-East Coast Institution of Engineers and Shipbuilders, having been informed by William Boyd, Esq., William Theodore Doxford, Esq., and Francis Carr Marshall, Esq., their Trustees, that they, the said Trustees, with the consent of the Donors, have invested with the Tyne Improvement Commissioners, upon a mortgage of the Tyne Consolidated Fund, for the period of ten years, at an interest of £3 12s. 6d. per annum, the sums of £274 and £331 held by the said Trustees in trust for the said Institution, and that such investment is not strictly within the terms of the instruments creating the Trust, this meeting sanctions, confirms, and approves of the said investment."

Mr. GRAVELL seconded the adoption of the resolution.

The PRESIDENT observed that the Gold Medals' Fund of £274 was due to the great liberality of three gentlemen, while the further sum of £215 for the Graduates' Award Fund had been obtained from the principals of some of the leading works in the district, and he hoped these bounties would bear very good fruit.

On being put from the chair, the resolution was unanimously accepted.

The President then delivered his Inaugural Address.

INAUGURAL ADDRESS

By the President, WIGHAM RICHARDSON, Esq.

[Delivered at the Annual Meeting, October 13th, 1890.]

Gentlemen,—By your indulgence I am permitted to address a few remarks to you at the opening of this, the seventh session of our flourishing Institution, and I beg you very sincerely to believe that the task is no easy one. In the first place, I succeed a President whose name is known through all the earth wherever a steamship floats, and in the second place, I cannot pretend to the special knowledge possessed by so many of those who are so good as to attend here this evening. How then can ignorance instruct knowledge, or the half empty pitcher replenish those which are full? But, even as a passenger on board a steamer may know nothing of navigation as compared with her captain, nor of machinery as compared with her engineer, and yet from his greater leisure, or, perchance, from his very ignorance of these matters, may be able better than the officers on board to give a succinct account of the voyage, so I summon courage to lay before you some notes, as it were, of the ocean of knowledge which we have, all of us, been recently traversing.

This Institution of ours has been in every way a flourishing one, and our Secretary has shown us in his report that intellectually and financially it is sound and healthy. May we hope that the present session will place us on a yet higher level.

During this year of our Lord we have had two gratifying testimonials to the esteem in which our Institution is held. The old and much respected and most influential body known as Lloyd's Register of Shipping has called upon us to name four gentlemen to assist their surveyors in the forming of the rules for the construction of ships and steamers, and your Council have selected two Past-Presidents, Messrs. Wm. Boyd and F. C. Marshall, as engineers, along with the well-known shipbuilders, Messrs. Robert Thompson, of Sunderland, and Henry Withy, of West Hartlepool. The duties will not be light, but the benefit to Lloyd's Register will, I feel sure, be even greater than their

Committee imagine. It has long been a grave defect in their constitution, and in that of the Bureau Veritas, that the counsels of those who know most about ship construction should have been to a great extent neglected. It is now twenty-five years since I personally began to agitate on this subject, and it is doubly gratifying to me to know that a solution has been at last found by leaving the election of one-third of the new Committee to our Institution.

A further gratifying event is that the Durham College of Physical Science has called upon us to nominate a gentleman to its Chair of Engineering and Naval Architecture. It is true that the necessary funds are not yet fully subscribed, but I have little doubt but that they will be raised, considering the munificence in the past of some of our local names.

It has often been remarked that this nineteenth century in which we live, and more particularly the reign of our beloved Queen, more resembles the times of the Tudors and of Queen Elizabeth than any other century of the Christian era. In the sixteenth century the time foretold by Seneca had come, when the ocean relaxing its bonds had revealed a new world. In our own days the locomotive, the steamship, and the telegraph have made a new world by transforming the conditions under which we live. Perhaps you will allow to one who is near his eleventh lustration to be to some extent the *laudator temporis acti*, and not expect from me a pæan on the wonders of our wonderful age. Although the future is full of hope, the past is replete with interest.

Last year it was my lot to visit the ancient city of Milan. Travellers who go there rarely fail to visit the cathedral, whose interior is reputed to be the most impressive in Europe, and another interior which far from being impressive has a barn-like appearance, and was until lately used as the guard-room of the barracks. But on the end wall of this room is a picture, some 30 feet by 12, which is so beautiful that it is the despair of artists even to copy it. I refer to the "Last Supper," by Leonardo da Vinci, painted 400 years ago; and I find that the painter was also an author and an *engineer*. Yes, an engineer, and his works endure until our time. He supplied the city of Milan with water, and made a navigable canal, 200 miles in length. He also designed various architectural works of great merit. Thinking on this, the reflection occurs, are we wise in specialising our knowledge so much as we do? It has been very justly said that a man may allow himself to know a little about a great many things, provided he knows a very great deal about

one thing, that is about his own special trade or profession. But surely the thorough knowledge of our own subject requires the knowledge of all kindred subjects. We engineers complain that our architects are wanting in a knowledge of the principles of construction, but how often do we see buildings put up by engineers themselves where they treat brick or stone walls as if they were cast iron cylinders, not to say girders, and forget that if steel be strong in tension and cast iron in compression, the strength of stone lies in its weight, although, indeed, a great authority has admitted that it is not so heavy as a fool's wrath! Some of our modern "triumphs of engineering," such, for example, as the roof of the St. Pancras Railway Station, will probably be looked at with more astonishment or pity than admiration by our children. We have been so taken up with the useful in our time that I feel sure that the great building age of Great Britain has hardly commenced. The learned historian of Italy in the fifth century, our fellow-townsman, Dr. Hodgkin, has described in a chapter which none can have read without a thrill, the glorious architecture of ancient Rome, and that Forum which no mortal it was said in future could hope to imitate. But I for one believe that the English will do better than imitate. They will, before the sceptre of empire shall have dropped from their grasp, far excel it. But for the present, alas! we are far, very far, from any such realisation, and the huge stones of Baalbec and the temples of Egypt are equally beyond our grasp. The hope of the future lies with those who do not mistake archæology for architecture, but who will be as original in their conceptions as our engineers are.

When foreigners visit England there are two things which always strike them painfully. The one is the sight of the ragged urchins in our streets, the other the ugliness of our provincial towns. To the first the Englishman is wont to reply that the moral status of our poor is improving year by year; to the second he will perhaps say that our towns if not beautiful are yet well drained and healthy. And in truth the expenditure on drainage and other sanitary works has been most laudable, and to have a town well drained is a great good. Even if a better system of disposing of our refuse should be ultimately adopted, it cannot but be of immense advantage to have our towns drained as they are. What you may choose to send down your drains is quite a different question, which must stand on its own merits. You will recollect that the recent outbreak of cholera in the province of Valencia, in Spain, was attributed to the sewage of a country town (whose name I forget) being allowed to run down an open ditch in the middle of the

main street. Here, in Newcastle, we carefully cover up the drain, and have openings at intervals, so that the wary pedestrian may, if he choose, dodge the noxious gases. Moreover, the abundant supply of water reduces the danger to a minimum. I have myself seen in a Polish village a proper heap of manure at the *front* door of every cottage, but in Newcastle we remove the refuse to the *back* of each house and place it in a midden and construct a back street (dear to the amorous Phyllis, if to no one else) so as to be able to cart it away when there is a sufficient accumulation. The able engineer, Mr. W. Geo. Laws, who now looks after these matters in our city, is, I believe, most anxious to introduce a better system, and has partially done so already. He has also furnished a destructor for getting rid of the refuse by fire. Some theologians are instant to remind us that refuse of another kind will ultimately be subjected to the same powerful agency. I have it on his authority that the area of these back streets in Newcastle alone amounts to over 60 acres, and a very simple calculation will show that the cost of making them must have amounted to from £50,000 to £100,000. If only the money had been spent in planting our streets with trees! As regards trees there is probably a sufficient width in our less frequented streets for a row of trees down the middle. It is understood, however, that our Town Improvement Committee far from considering the planting of trees to be a duty, are rather haunted with the fear of being made responsible should some fool or drunkard injure himself by running against them.

The whole system of removing night-soil merits close study. Dr. Wilson, of Wallsend, has introduced a plan which is very well spoken of, and which seems at least a step in the right direction. The system of Mr. Moule has never made the progress it might have done, because his appliances have not been designed by a mechanical engineer, and very soon begin to give trouble. The town of Rochdale, in Lancashire, has adopted a system for which extraordinary results are claimed. I have before me a report, in which it is stated that in consequence of the new method the death-rate has been reduced from 26 per thousand per annum to 19, and an annual saving is claimed of £36,000, and this in a population of a little over 70,000. Apply these figures, please, to the population—one quarter of a million—of Newcastle and Gateshead, all ye who wish to reduce the rates.

These questions are to my mind eminently questions for engineers, and equally so is the laying out of streets. No street can be beautiful that is a straight line; all the streets known in the world for their beauty

have a bend or a curve. We may proudly instance our own Grey Street. The Boulevards in Paris, the Ring in Vienna, and even Regent Street in London, are equally instances to the point. The historian of New York informs us that the streets of that city were laid out by the cows, which animals certainly had a better eye for beauty than the authors of the chequer board system now so much in favour in America. This is a system which has the practical inconvenience, moreover, that to get from the corner of the board to the centre, each successive zig-zag added up will equal in distance the full length of one side of the square.

In one respect, however, the Americans are before us. From very early times—in fact, from the date of William Penn—they have been careful to lay out what we may term "limits of deviation," and no builder has a right to build upon ground thus dedicated as a public thoroughfare of the future. It would seem that there is a need for some legislation on this head in England, so as to give larger powers to the municipal authorities. Under the present system, even wide streets laid out by our forefathers are encroached upon and spoiled. I would instance the great boulevard of London known as the City, the Euston and the Marylebone Roads, where the original width is being gradually and lamentably encroached upon; and to those of you who know Newcastle, I need only mention, as deplorable instances of want of foresight and of wasted money, Westgate Hill and the Scotswood Road, near the Elswick works. A width sufficient for an ordinary street is far too little for a main thoroughfare, and doubly so if tram lines have to be laid.

But you will say what has the planting of trees to do with engineering? The answer may be given in another question—what is the use of planting trees, if our engineers kill them with their smoke? And this brings us back to the point that no one can thoroughly know his subject unless he studies also subjects kindred to it. Seventeen years ago Lord Armstrong (and can I quote a higher authority?) said, in the hearing of many of us—for it was when President of the British Association—that he could state with perfect confidence, from the result of experiments made in conjunction with Mr. Longridge and the late Dr. Thomas Richardson, that so far as the raising of steam is concerned, the production of smoke is unnecessary and inexcusable. Since that time, I ask you, what is the progress which has been made? Go and stand on the top of any neighbouring eminence when there is an easterly breeze, and watch the great volume of smoke which rolls up the valley of the Tyne; or travel from Liverpool to Leeds by the Lancashire and Yorkshire Railway on a fine summer's day, and mark the smoke from the unending chimneys, and the

grimy black pall which hangs like the trail of the serpent over the lovely valleys of the Pennine range. Can nothing be done to remove this grimy cloud, which blackens our bodies and depresses our minds? Yes, I think there is hope, and in several directions which I will indicate, if you grant me so much patience.

What Lord Armstrong referred to was, I presume, the more perfect combustion of the carbon of the coal, for smoke itself may be considered to be unconsumed carbon. But when this has been done, we are far from having cured the whole evil. Most of you will know how grievously all vegetation used to suffer from the fumes of the alkali works; but in the last few years, partly owing to the sad decadence of that industry and partly to the more stringent and more scientific application of the Alkali Fumes Act by the present Government Inspector (Mr. Alfred E. Fletcher), we can all of us see that in places out of the actual hollow of the Tyne trees and hedges are again beginning to grow. Mr. Fletcher is convinced that by a scientific testing of the gases as they leave the bridge of the furnace much can be done to cure the evil, and he has formed a society called the "Association for Testing Smoke Preventing Appliances," the object of which will be to test (and as I understand, at the expense of the inventor) all patented appliances for the consumption of smoke which any patentee may wish to have so certified. Many of us have had disappointing and costly experiences of patent bars and so forth, and it will clear the way very much to know from an impartial source what any given apparatus does and does not do; and I hope the association may receive a cordial support in this district. When once it can be shown that smoke is not really necessary in carrying on manufacturing operations, we may expect our rulers to put in force the laws already existing, and to legislate further in the same direction.

Again, the introduction of artificial draught raises visions of the abolition in the future of high chimneys. On board steamers at sea a very great desideratum is a good system of mechanical stoking. In the steamers on the Russian coasts, where astatki is burned, they have no need for stokers at all. Some of you will have read the graphic picture, by Mons. Alphonse Daudet, of the life of a stoker at sea in his interesting novel called *Jack*. The picture may, perhaps, be overdrawn; but we cannot doubt what an advantage it would be to perform this function mechanically.

But perhaps the most hopeful direction of all is in the chemical treatment. We know how the heated nitrogen and the carbon oxides, which used to be belched forth from the blast furnaces, are now used to raise

steam in the boilers which supply the blowing engines; but Mr. Ludwig Mond, of the firm of Brunner, Mond, & Co.—the same who has introduced the Solvay process for making soda, and in so doing has hit many of our friends so hard—has, as I understand, gone much further. He burns his coal with artificial draught, and conveying the gases into a chamber, he washes them with water spray, which causes every particle of soot or smoke to be deposited, and at the same time condenses and recovers the ammonia (a product of nitrogen and hydrogen) as well as the sulphurous fumes. I trust I have not misunderstood Mr. Mond's figures; but I gather that, to get an equal efficiency of steam-raising power, he has to burn 125 tons of coal in place of 100 tons, and for every 125 tons of coal burned he recovers 4 tons of sulphate of ammonia. The fuel, if cheap (say 5s. a ton), will cost £31, and the sulphate of ammonia, at £12 a ton, is worth £48. If results such as these can be attained the doom of smoke is sealed!

The late Sir William Siemens approached the question from the same point of view, and showed that if coal were freed from its bye-products it would be a better fuel as a fuel, and the bye-products themselves would be worth twice as much as the original cost of the coal. I will not weary you by going over his methods, but would remark *en passant* that the introduction of electric lighting and the spread of cooking by gas and by petroleum are every day making the application of these methods more feasible.

I am pleased to see that we shall have a paper during the session on some points connected with electricity, and I trust that the author will treat of the sources from which it may be derived. The present roundabout system whereby the coal is first wastefully burned to cause heat, and the heat applied to raise steam, and the steam uneconomically applied to drive an engine, which in its turn causes a dynamo to revolve, evidently leaves great scope for invention. Perhaps the weakness of accident may be strong where the strength of design is weak. It is generally considered that electricity may be generated by the oxidisation of an electro-negative in the presence of an electro-positive. Now, carbon is positive to all other known substances; and carbon is being oxidised—that is, consumed—every day and everywhere. It is imagined by many that some day a substance electro-positive to carbon may be found, and that then we shall have solved the problem of producing electricity economically. In the meantime, Mr. Mond, in condensing his ammonia as above described, has found that he can so manipulate the gases along with platinum as to form a very powerful battery. Time and my own

ignorance forbid further notice of this, except to refer to the brilliant experiments of Lord Armstrong more than forty years ago, when he evolved electricity by causing steam to impinge upon different metals.

In connection with sanitary legislation may I notice the great attention paid to the ventilation of public buildings and private rooms. Probably it will be found that there is good ground for the prevalent belief that the fresh air should always be brought in at the top, and the foul air taken out at the bottom of the room. At least I know no more comfortable plan than an open fire and either the window opened half an inch at the top, or the adoption of what are called Tobin's tubes. The open fire and its chimney form the upcast shaft drawing the air from the bottom of the room. For rooms such as that in which we now, by the liberality of the Literary and Philosophical Society, are holding our meetings, and which enjoys an unenviable notoriety for bad ventilation, it will always be difficult to make any satisfactory arrangement on account of the want of height; but I trust that a crude scheme which has been proposed to cause air, by means of a fan, to come in from under the seats will not be adopted without the most careful pre-consideration.

The supply of pure water to our large towns has been making good progress, and the towns in this district are in a fairly satisfactory condition. It is the abundance of our water supply which alone makes our system of removing night-soil endurable. The great works for taking the water of Thirlemere to Manchester, and the water from the head sources of the Severn to Liverpool, are making rapid progress towards completion. Many of you doubtless have admired the good taste of the architectural features of the great reservoir in Wales. London in the meantime contents itself with water pumped from the Thames and from the gravel, along with the water brought by Sir Hugh Myddleton 270 years ago from the great Chadwell spring, which rises in the meadows between Hertford and Ware. It may be interesting here to note that the annual dividends of Myddleton's Company have gradually risen from £15 to £380,000!

The valuable project of the late R. S. Newall to bring the water of Ulleswater to Newcastle is still looked forward to by some. By the kindness of Mrs. Newall I have here the plans which he prepared, and which some of you may care to examine. At the other end of Europe the modern Athenians, finding that to ensure a full supply of water during the summer months they must seek it from the eternal snows, are preparing to construct an aqueduct from the Lake Stymphalos, near the centre of the Peloponnesus. The distance is nearly 70 miles, and it is an ambitious work for so poor a country.

The construction of canals has recently attracted a great deal of attention. The great success—the extraordinary success—of the Suez Canal, the construction of which is due to the talents, the energy, and the perseverance of Mons. Ferdinand de Lesseps, makes us regret all the more the *fiasco* of the Panama Canal. The Panama Canal will probably not be completed at least in the lifetime of most of us. Although perhaps one-half of the way has been pierced, two great obstacles remain, towards the removal of which but little has yet been done. The one is the dredging of a channel from the Panama shore out to the deep waters of the Pacific, a work in itself perhaps as great as the dredging out of the Tyne from Tynemouth Bar to Blaydon, and we all know what that has cost in time and money. The other is the cutting through of the Culebra Hill. If you will start from the Quayside of Newcastle and walk up Westgate Hill, along the military road made last century by General Wade (the "judicious" Wade, he who destroyed the Roman Wall in order to make a foundation for his road), and if you will keep on to the reservoir at the crest of the hill, near to the residence of Mr. John W. Pease, and then walk on down the hill to the Denton Burn, you will have gone over just about the distance of the Culebra Hill cutting, and will have mounted to within 10 feet of its height. As the ground at the Isthmus is treacherous, the slopes must in consequence be very wide, so that the amount of excavation will be enormous. Indeed some engineers have maintained that it would be better to attempt a huge tunnel. If, however, a tunnel were even practicable, it would hardly be risked in a region where earthquakes are so prevalent; and probably a system of locks will have to be resorted to.

In connection with Mons. Ferdinand de Lesseps, I feel bound to take this opportunity of referring to a difference of opinion between myself and my very old friend, Mr. Jeremiah Head, because the matter has been made public by appearing in the *Transactions of the Cleveland Institute of Engineers*. In the correspondence referred to I stated that our great fellow townsman, the late Robert Stephenson, had admitted the feasibility of making the Suez Canal, but only doubted whether it would pay an adequate dividend, because sailing ships would never use the canal, and in his time cargoes were transported in sailing vessels almost exclusively. Mr. Head on the other hand maintained that Robert Stephenson went much further than this. After reading various matter which, by the courtesy of Mr. James Forrest, the Secretary to the Institute of Civil Engineers, has been kindly put at my disposition I am bound to admit the substantial accuracy of my friend Mr. Head's contention.

Mr. Forrest has been so good as to write for me to an old friend of Robert Stephenson's, Mr. B. P. Stockman, who, in an interesting letter, sums up the matter thus:—

"The opinion of Robert Stephenson was that the necessity (admitted by his colleagues) of a difference of level between the Mediterranean Sea and the Red Sea, sufficient to afford a natural scour, was of paramount importance, that without it the canal, if cut, would silt up, and get choked with sand, that vessels would ground, and in fact it would be like a *stagnant ditch*, unless at an enormous cost it were artificially cleared by constant dredging or other processes."

Mr. Stockman adds:—

"That these predictions have been fulfilled the account of the early opening of the canal will show. How the difficulty has since been overcome is another matter."

But if the Panama Canal is, for the time being, a failure, there is better hope for the Nicaraguan Canal, which our American cousins are attacking with their accustomed energy. I don't know where you will find a better account of the country to be traversed by this canal than in a very charming book, written many years ago by a late fellow citizen, *Belt's Natural History of Nicaragua*. It is a route with good approaches from the sea at both ends, a river (easy to be canalised) or a lake for the greater part of the distance, and for the rest, solid rock, with an abundant supply of water. It is intended, I believe, to have five locks of a novel construction. Instead of gates there will be huge caissons, which will be drawn back (after being partly floated) on rollers into recesses at the sides. There appears to be no good reason against making the lift of each lock 50 feet or 60 feet, or even more, for there is practically no limit to the strength of the caisson. The Americans have also an ingenious scheme for saving the water for the locks in case of any scarcity, by allowing it to run into successive trays or reservoirs in steps of 10 feet each, so that if there be ten steps not more than one-twentieth of the water need be run to waste.

There was another scheme for crossing the Isthmus at Tehuantepec—that of the late Captain Eads, the well-known engineer of the St. Louis Bridge and of the Mississippi Bar, and although that has not been carried out yet, the principle is being applied in the ship railway across the Isthmus of Chignecto, at the head of the Bay of Fundy. So even the Acadian land "by the shores of the basin of Minas" is to be invaded by the modern engineer. Does not such a project, which is far advanced already, recall the line of Horace—

"Trahunt que siccas machinæ carinas?"

Another development of canal engineering is the system adopted by Messrs Clark & Standfield in Belgium, where they lift a section of the canal itself, with the barges floating in it, by hydraulic presses, from one level to another. I am informed that at one place they do in one lift what formerly required fourteen locks.

It is well known that the older canals in Great Britain have proved very profitable undertakings, and doubtless a great deal can be done to render them yet more efficient. The system of discharging barges *en bloc* into steamers, adopted by Mr. Bartholomew at Goole, will be familiar to most of us, and it is probable that horse traction will sooner or later be replaced by steam or by electricity. If this be attempted, it is thought that it will be found advisable to limit the speed to something very little higher than that attained by horses, on account of the destruction of the banks.

The Manchester Ship Canal is rapidly approaching completion, and steamers have already been built with masts arranged to go under the bridges. The works on the Isthmus of Corinth Canal which had been abandoned when I visited them last year are now recommenced, and the canal which is to unite the Baltic with the German Ocean is making good progress. The Birmingham people are also projecting a ship canal to the sea; and who knows but that the scheme of our colleague, Mr. Andrew Leslie, of joining the Irish Sea to the German Ocean may not yet be realised?

Now, all these schemes are bright tokens of the development of our civilisation. There is nothing material which tends to progress so much as the making of roads. The late Richard Cobden attributed the backwardness of Ireland partly at least to its never having been conquered by the Romans, and to the absence of Roman roads. In our days we seek to pierce the land with water, and to cross the water by bridges. The Forth Bridge and the great Suspension Bridge at New York must be named as the greatest works of their kind in this, or in any age. The designs of both have been subject to some adverse criticism, but we may very well wait till the critics do any thing better, or so good.

It is pleasing to note in bridges of less ambitious span a tendency to employ stone and bricks more than iron girders, and as this construction spreads, we shall, doubtless, find our engineers recognising the superiority of stone voussoirs over the readier and cheaper, but far inferior brick. If you will look underneath the arches of the viaduct which crosses the Newcastle road at Durham you will see evidences of this.

Besides bridges, we have been made familiar with extraordinary tunnels. The Mont Cenis and the St. Gothard tunnels are probably the

precursors of many others. Railway trains now go under both the Bristol Channel and the estuary of the Mersey, while Sir Edward Watkin proposes to take us right under the Irish Sea and the English Channel. The latter project stands in abeyance from political reasons, and while it stands in abeyance some schemes for carrying whole trains across the Channel, according to the system so largely adopted in Denmark, have been allowed to drop. My own firm has built steamers for carrying trains both for Denmark and for Prussia, and in both countries the system has been very successful. Those of you who have crossed from Folkestone to Boulogne must have noticed how admirably the system works of lifting the whole top of the passenger luggage vans on board of the steamers, and then transferring it without unpacking on to the train for Paris, and, granted that good harbours are made, there seems no reason why goods trains, and even passenger trains, should not be carried across on the deck of powerful steamers.

In marine engineering progress has been steady, even if slow. Thirty years ago although the scope of Watt's great improvements was understood, and although the compound engine had been introduced by Woolff, yet so it was, that but little attention was paid to anything but mechanical contrivances. It was known that heat and force are strictly correlative, but it is only step by step that this knowledge has been applied. As has often been the case before, I think two popular works, viz., Professor Tyndall's lectures on "Heat as a mode of motion" and the late Professor Clerk Maxwell's charmingly written work on the *Theory of Heat*, have had much to do in familiarising and bringing home to the minds of all, truths which though admitted had been largely neglected. James Watt saw the waste of heat involved in uselessly at every stroke heating the cylinder by steam and cooling it by the condensing water, and he showed us how to condense the steam in a separate vessel. Quite recently we have come to realise the loss of heat arising from admitting the steam into a cylinder which had previously been cooled by allowing the steam to expand to a lower temperature, that is, to a lower pressure. Hence, the steam has been expanded in stages of two cylinders, and later in three cylinders, with a very marked economy. Along with this, higher pressures have been used.

There is no manner of doubt that a great economy must follow the adoption of four cylinders, and that they will come into use so soon as they can be arranged without undue complication, with a ready accessibility of parts, and without any great increase of weight or space; and I may say parenthetically, that my friend and partner, Mr. John Tweedy, claims to have succeeded in fulfilling all these conditions.

These considerations are but another instance of what I started by saying that the engineer cannot afford to neglect any of the cognate sciences.

Still further to avoid the loss of heat, Professor Kennedy, late of University College, London, has proposed to coat the internal surfaces of steam cylinders, or at least those parts of them which are not exposed to wear, with some substance which shall have less conductivity than cast iron. He anticipates a very great diminution of condensation. In a popular way we may compare this with the coating of the internal iron-work of a ship with cork paint, which is known to prevent to a very great extent the condensation of the moist vapours.

When all is done, however, we still lose from 80 to 90 per cent. of the power of the coal which we burn. Whether we should be humiliated by our want of success, or consider that this is all part of the lavish expenditure which seems to characterise the works of the Great Master of all, who shall say? When we reflect, for example, on the innumerable seeds for the propagation of animal and of vegetable life, and how great a proportion of them seem to be wasted, or look at the vast satellite which, as far as we know, is an otherwise useless volcanic mass, and serves only as a lamp to light up our earth when the sun is below the horizon, we may well say "such knowledge is too wonderful for us."

I asked a young Cambridge friend to report on the relative economy of gas engines and steam engines; and if I rightly understand his figures, it would seem the presence of four parts of nitrogen to one part of oxygen in the atmosphere has some resemblance to the well-known difficulty of latent heat, and in somewhat the same proportions. Still, if the theoretic economy is, off and on, not far different from that of steam, there should be a great future for gas engines, considering that you save stokers, boilers, boiler seatings, and chimneys, and in fact you can turn a tap and go ahead, just as if you were going to light a gas jet. On the other hand, there is the difficulty in starting, for a revolution and a half must be made before the gas engine will work, and also the motion is much less regular. There would seem to be a need for a vessel separate from the cylinder in which to accumulate the pressure, and the need once pointed out, the contrivance to effect it will probably sooner or later be hit upon. From the point of view of absence from smoke the gas engine and the petroleum engine are to be cordially welcomed.

How many of you can remember, as I can, going to Edinburgh by coach, or can recollect the old wooden station at the foot of Rye Hill, where we used to take tickets for Carlisle, and which is now removed to a part of Gateshead, and converted into dwelling houses! Our Central

Station, designed by John Dobson the architect, though one of the earliest of our railway stations, is still one of the most satisfactory, and has served as the model and type for one of the most recent of our great stations—that outside the walls of the ancient city of York.

Thus in one short lifetime the railway interest has become one of the most important existing, but whether as regards the permanent way or the locomotive there has been but little in the way of radical improvement since the days of the Stephensons. Both have been increased in weight and perfected in details, and the material of the rails is made from steel or ingot iron, in lieu of puddled bars. Here again we owe very much, or almost all, to the chemist. The bogie locomotive has been largely introduced, and on two of our main railway systems, namely, the North-Eastern and the London and North-Western, the steam is expanded through two cylinders, on what is known as the compound system. Mr. Webb, at Crewe, uses two high pressure and one low pressure cylinder, working on different crank axles, which, by the way, are not coupled together, but find their own angle by natural selection; whereas Mr. Worsdell, at Gateshead, uses only one high pressure and one low pressure cylinder, both of which work on one and the same axle, the cranks of which are at right angles, as in marine practice. I believe the results from both systems are very satisfactory.

The use of coal instead of coke on our railways has become general; but it is not clear that this is altogether an unmixed advantage, and our district remains the only important manufacturing centre which is served by only one railway company.

The machine tools by which our engines are manufactured are every year being perfected; and some of them, it has been pleasantly said, seem to be able to do everything but think. It is a matter of regret that so few of them are made in our own district. The carriage of a heavy machine from Manchester, or Leeds, or Glasgow, comes to a very respectable percentage on its cost; and very likely, moreover, the greater part of the crude iron and steel employed in its construction is taken from Cleveland to the place of manufacture. Further, the machine-maker ought to be in close touch with the user, so that from every point of view we might expect success to await a manufactory of heavy machine tools if established on the banks of the Tyne, the Wear, or the Tees, especially when it is remembered that on these three rivers is one of the very largest markets for their sale.

It would not be reasonable to expect equal success from the manufacture of textile machinery, nor of bicycles, for instance. These latter aids to locomotion are an exemplification of what may be done by the perfec-

tion of details. Bicycles were in existence when I was a boy; but it is only quite recently that they have come into general use, with results that are quite astonishing. The number made is prodigious, and has raised up Coventry from its industrial depression; while the dear old country inns, the delight of our forefathers and the theme of Shenstone, are being gladdened by the visits of the cyclists in search of health and relaxation. A great deal of the success of the bicycle is due, I am told, to what is called the ball joint or frictionless axle-box, and it would be very interesting to have a paper on this subject and a discussion as to how far the principle might be adapted to axles or shafts of larger size.

The transmission of power from a common centre to motors at a distance is a question of great interest. For a long time the system introduced by Lord Armstrong of hydraulic pressure held undisputed sway, and perhaps it is still well in the front. If any of the staff of that great establishment would give us a paper on the subject, it would be very welcome. The competing systems include compressed air, gas, and perhaps above all, electricity. One of the most notable instances of transmitting power from a centre is to be seen at Deptford, where M. S. Z. de Ferranti is building two dynamos, each with armatures 42 feet in diameter, and each driven by engines of over 10,000 indicated horse-power, the weight of each engine and dynamo complete being approximately 1,000 tons. M. de Ferranti has kindly sent me a section of his concentric tubular mains, each of which is capable of taking 2,500 horse-power of electricity. Thus four mains will be required to each 10,000 horse-power dynamo. I will leave this section at the offices of our Institution, and I think you will agree that it excites our surprise and merits our close attention.

Shipbuilding, since the introduction of iron ships, has increased enormously in our country; so much so as to be the envy of our neighbours, some of whom have attempted, by bounties and other fiscal measures, to induce their own subjects to build their ships at home. In the details of construction there has not been much radical advance in recent years. Steel—*i.e.*, iron made from ingots—has replaced the puddled material in the majority of cases, and water-tight double bottoms have added considerably to the safety and at the same time to the usefulness of the steamer. Most of the vessels built in this country are classed at Lloyd's, and the apportionment of the material is regulated by their rules, which, it cannot be too often repeated, are unfortunately and unintentionally a premium on inferior models. Lloyd's rules for the framing, etc., of a ship are approximately based on the *girth* of the midship section measured

up *to the deck*, with some handicapping in favour of square bilges, while the plating, etc., is regulated by an approximation to the *surface*, also measured *to the deck*, and also subject to handicapping in favour of models of box-like form. The basis of these regulations is bad enough in itself, and it is made worse by the action of our Government, which fixes upon a maximum load-line beyond which British shipowners cannot load their vessels. This restriction does not apply to foreign steamers, not even when they load in British ports. In my position I cannot very well say all that I know about foreign steamers and their loading; but that they do load deeper than the regulation load-line is a matter of notoriety. We cannot doubt but that our shipbuilding colleagues who have been elected to the sub-committee of Lloyd's will take this matter up, and see that it is put right—so far, at least, as Lloyd's are able to put it right. What I personally have always contended for is, that the load-line should be a *condition of the classification*, as it is now with awning-decked steamers, and that if scantlings are to be based on the girth and the surface, that the girth and the surface respectively should be taken to the load water-line and not to the deck, and that then what are called the numerals should be adjusted accordingly.

In naval architecture, as a branch distinct from ship construction, we may note the improved system of testing by weight the initial stability of vessels, and the clearer views on what constitutes the resistance of a ship propelled through the water. Thirty years ago, the idea was prevalent that the resistance is due to the cleavage of the water, as if the ship were a wedge. Extreme importance was attached to the angle of the entrance and stern lines and to their exact curve, and a narrow beam was regarded as essential to speed. But, recently, owing to the investigations of the late Professor Macquorn Rankine, and to the experiments of the late William Froude, and to the clear expositions in his Manual of Naval Architecture by Mr. W. H. White, the Director-in-Chief of Naval Construction, and a member of our Institution, it has been admitted that for *slow speeds*, say, for ordinary mercantile speeds, and in *smooth water* the resistance varies approximately as the *surface*, provided always that the surfaces in two cases are equally smooth, for a very slight degree of fouling will increase the resistance most materially. Now, to all who have any knowledge of mathematics, it will be evident that for similar forms the commonly received expression $D^{\frac{2}{3}}$ where D stands for the displacement, means nothing more nor less than the *surface*, and it is an expression peculiarly convenient to the ship designer, because, in designing any vessel, the displacement is usually the very first quantity which has

to be ascertained. For this reason, it would be convenient if Lloyd's rules also recognised the displacement with due regard to the dimensions, as a basis for scantling, and such a basis would also be fairer to the finer-modelled ships. May I repeat that this law of resistance varying directly as the surface is only accepted for speeds so slow that no bow wave is raised and in smooth water only. In a sea-way the advantages both of absolute length and of relative length and fineness must be granted, and, against a head sea, the short and stumpy steamer makes but poor progress.

The fact that as you increase the dimension of a vessel, you increase the displacement as the cube of the dimension, and the resistance as the square only, throws a light on the satisfactory speed results attained by large steamers.

As regards resistances at high speeds, there is by no means so clear a view; and the Admiralty, and also Messrs. Denny, of Dumbarton, test the resistances by models in tanks, according to the method of the late William Froude. This is a costly and tedious, though, perhaps, an efficient method, and we can only hope that, after some years of experience, sufficient data will have been arrived at, upon which to found the laws of resistance at high speeds. Those naval architects who have not the advantage of an experimental tank are reduced, in effect, to a guess, founded upon experience, of the value of the coefficient applied to the formula—$\frac{(\text{displacement})^{\frac{2}{3}}\ (\text{speed})^{3}}{\text{coefficient}} = \text{indicated horse-power}$. When all is done, however, and by whatever method the resistance may be estimated, there is still the further element of uncertainty arising from the varying efficiency of the propeller.

Twenty-five years ago, there seemed every probability that we should adopt the decimal system of weights and measures, devised in France at the time of their great revolution. The system has been accepted by most of the Latin nations both in Europe and America, and also by the new German Empire. It has not been adopted, however, either in Great Britain or in her colonies, nor yet in the United States, nor in Russia, nor, so far as we know, in China. The system has much to recommend it, especially for scientific calculations, and it gave some hope of a universal, world-wide, common standard, but this is now more likely to be reached in our own system, or in a modification of it. On the other hand, there is urged against the decimal system that it is less suited to the ordinary details of daily life, and even in France you find that inches, and pints, and pounds, and fathoms, and feet, and leagues, and geographical

miles are still used in conversation and in books of general literature. In Victor Hugo's popular novel, *Les Misérables*, I noticed that the decimal weights and measures are never once mentioned. Certainly the English always seem to have a greater grasp of what their units mean—a more concrete conception of them, if such a phrase may be permitted. A mile for itinerary measures, a yard for building sites, a foot in shipbuilding or joiner work, a hand for horses, an inch for smaller measures, have all a clear and familiar meaning in our minds.

Again, the decimal system would rivet tighter the chain of the decimal notation, which is admittedly inferior to the duodecimal. The Englishman who has mastered his pence table has a power in mental arithmetic which will astonish a Frenchman. For a similar reason, the elder Rothschild, who had been used to the endless intricacies of the old German coinages, used fairly to surprise the members of the London Stock Exchange. From this point of view the contention of those who claim that the decimal system would shorten by 75 per cent. the number of years necessary to learn arithmetic falls entirely to the ground, and, in fact, leads to an opposite conclusion. This contention comes especially badly from one advocate at least, who is in favour of keeping boys for years in wearyingly learning all the intricacies of the Greek accidence in three or four dialects, on the ground that it is a species of intellectual gymnastics and an incomparable training for the mind. From my own humble experience I could give many instances of the errors that I have seen arise from the use of new-fangled measures, and the most recent occurred lately in my own house where the cook was ordering some new pie dishes, and having got hold of a yard measure with inches marked on one side and centimetres on the other, gravely ordered half-a-dozen pie dishes, 37 inches long! As a matter of history it is interesting to record that the only time when the bill for adopting the decimal system seemed to have a chance of passing the House of Commons, a pamphlet was circulated at the instance of the society which tries to prove that the English are the ten lost tribes of Israel, and which argued that the new system was contrary to the Bible. There were plenty of members in the House who disliked change instinctively, and were as glad of an excuse as were the Tories in the time of Queen Anne to avail themselves of Sacheverell's sermon in order to bring about an end to the Continental wars.

One other department of engineering for which our city is famous, namely, the manufacture of ordnance I shall ask you to excuse me from entering upon, partly that I have no knowledge whatever of the

subject, but mainly because it has, but the other day, been so ably treated at Leeds by Captain Noble, who is one of the greatest, if not the greatest, living authority on the subject.

The use of mathematics in our profession is twofold—mathematical calculations are as a good tool in the hands of the skilled workman—mathematical study enlarges and ripens the mind. An enthusiastic friend of mine once said to me that when he had passed through the binomial theorem he felt as if he had passed through a tangled forest and reached the brow of a precipice and saw the "landscape below him, sun-illumined, with shining rivers, and cities and hamlets." Indeed, it is difficult to conceive any mind to have been fully trained without the study of mathematics. Mathematical progress since the times of Newton and Leibnitz has not shown, I think, much radical change, and the recent investigations into the geometry of four dimensions and the square root of minus one have not as yet given results immediately applicable to engineering. In scientific treatises there is a growing and a very laudable custom to supplement algebraical demonstrations with geometrical and even mechanical illustrations. Any object whatever is always better comprehended when seen from more sides than one. No less an authority than the designer of the Forth Bridge is credited with finding the centre of an irregular figure, by cutting it out in cartridge paper, and balancing it on the point of his penknife. I trust he will not think I do him an injustice, as I certainly mean none. An American author who studied for the classical tripos at Cambridge, at a time when at least some mathematics were required even from classical men, complained that in the mathematical question papers there were no *pictures*. The woodcuts in Euclid undoubtedly enable a certain class of minds to comprehend what eludes their grasp when stated in an algebraical form. Not long ago a German mathematician died, by name Jacob Steiner, who wrote a series of papers founded on the writings of Apollonius of Perga, who was a contemporary, I believe, of Euclid. Steiner's writings were not much esteemed in his lifetime, but after his death other mathematicians have collected and edited his papers, which (so far as I can learn) really mark a new departure in mathematics, and amount to the invention of a new calculus. It is a system of projection, and is sometimes called projective geometry, and it is said that the most difficult problems, such as can hardly be tackled by the differential or the integral calculus, may by this system be solved by means of a straight edge and a sheet of drawing paper. The subject seems to be but little known in England, and what I have heard of it myself has been from my relative, Dr.

Theodore Merz, of this city, and from Sir Robert Ball, of the Dublin Observatory, who is so honourably known in this theatre.

At the beginning of these, my remarks, I spoke of the Chair of Engineering at the Durham College of Science, which leads me to address a few words to our Graduates. Much has been said of recent years about technical education. The expression has been much abused, for technical education can surely only mean the teaching of an art. I can understand the institution of dairy schools to teach dairymaids more scientific methods of making butter, or schools of forestry, and so forth ; but in our own arts I can conceive of no better school than the workshop. You have there the experience and the skill of the best artizans, you have the feeling of being engaged in serious constructions, you are in the very atmosphere of your craft. More than this, you are learning by doing. There is the learning by committing to memory, and there is the learning by doing, and of the two, perhaps the latter is the better education. Some of the most successful men whom I know in other walks of life have been educated in the workshop. The workshop will develop some faculties in a way that Cambridge or Oxford cannot touch. But when your years of apprenticeship are over, or during them, you will do well to add to your practical knowledge all that you can cull from the schools of science. Nor should you neglect the study of modern languages, which are not difficult to acquire if you have a hearty will to do so, and if you learn by the ear rather than, or as well as by the eye. You have before you a long and toilsome way, but at every step you will find a reward. Work itself is a pleasure, and his life is a happy one who learns to love work. My friend, Mr. Joseph Cowen, once aptly said in one of his speeches, "Happiness is not a thing, it is a mental state. It is seldom found by those who seek it most, but it rarely fails to come to those who do their duty." And be assured that in the earnest pursuit of a noble profession you will, amid all the toil, find joys and a "life which bloated ease can never hope to share."

Mr. Wm. Boyd said, the duty had fallen to him that night to propose a vote of thanks to their new President for the very eloquent address which he had delivered to them that evening. There was only one complaint that he felt disposed to make, and that was that the address, so varied in its character, and so wide-reaching in the topics upon which it had touched, had not been in the hands of the members in some shape or form before hearing it read to them. But be that as it may, he was

quite sure he spoke the minds of all those present that evening, when he said that they had listened to this very able address with the utmost pleasure and satisfaction. There was to himself, personally, this one great gratification, that as the value of the papers read before this Institution had increased in importance and interest from the time the Institution was formed six years ago, he was specially pleased to find that the presidential addresses had also gone on increasing in interest and importance, and he ventured to think that the successors of their worthy President would have a very difficult record to beat when it came to their turn. The topics that had been treated with so much grace of language in Mr. Richardson's address were so varied that he found it extremely difficult to touch upon any one of them. In fact, he thought that that was hardly necessary: that was not, perhaps, the spirit in which an address of that sort was conceived or written. The spirit in which such an address as this was laid before them, seemed to him to be that of the enumeration, in a very talented way, of the various subjects to which members of this Institution might, more or less, turn their attention, and though their present President had wandered further afield than any of his predecessors ventured to do, yet that was, perhaps, a great advantage to the Institution; at any rate, whether it be an advantage to the Institution or not, or followed up by the Institution or not, it certainly showed they had been fortunate in securing as President for the ensuing year a man of very great grasp of thought, very great grasp of language, and who, they felt sure, if his health was spared to him, would preside over the meetings of this Institution with an ability which was indicated in the paper they had heard from him that evening. He did not know that he had more to say at present. He was quite sure that before he put the resolution it would be the wish of others present to supplement what he had said, and what his friend, Mr. Marshall, was going to say. There was no further formal business before the meeting, and, therefore, he hoped they would not necessarily confine themselves to the formal resolution.

Mr. F. C. MARSHALL said, he had very great pleasure in seconding the proposition made by their premier President, Mr. Boyd. Their best thanks were due to Mr. Richardson for his very able address. He had taken them all round the world of engineering pursuits, and he had done it in a manner which could not fail to be interesting, and, above all, could not fail to be very suggestive to the members of this Institution. They had never before, he thought, in any presidential address, or any other address, had anything in relation to sanitary engineering brought be-

fore this Institution, and he was quite sure that sanitary engineering might very well and profitably be studied by mechanical engineers. There was a great deal of mechanical engineering required in sanitary engineering, specially in matters of drainage, also in canal engineering, bridge engineering, and the various classes and phases their President had mentioned. In treating upon all of them, much which he had said was very suggestive, and especially so to their younger members. He had taken them all over ground that was entirely new to the Institution, and which, he hoped—he was sure he spoke the feelings of the Council—would be dealt with in many of the papers of the future. There had been a little disposition in their proceedings to restrict their papers to what might be denominated more especially marine engineering and naval architecture. Their Institution had a broader scope than this, and he trusted the suggestions of the President would be followed by good papers on many of the subjects he had mentioned. He did not think he should trespass longer upon their time after the admirable remarks Mr. Boyd had made in proposing the resolution. He felt it would be trespassing on their time to say more. Perhaps they would permit him just to add one word of indorsement to the very eloquent terms in which their President had brought forward the Graduate section of the Institution. Unfortunately, he did not see that night very many of their Graduates present. He thought it would be well if the senior members of the Institution would take this Graduate subject up rather more vigorously than they had done in the past. The Council of the Institution was willing to offer inducements to the members of the Graduate section for the production of good papers—two of those already read he heard spoken of very favourably indeed, and were said to have been worthy of the larger Institution. He hoped the stimulus of prizes, which would amount, he supposed, to something like £8 a year, would make the younger members of the Institution take a very earnest part in the conducting of the Graduate section. He could not say more to them, but had very great pleasure in seconding the resolution of his friend, Mr. Boyd, and trusted his suggestion that other members would express their views on this very admirable address would be followed.

Mr. JOHN PRICE said, not one of them, he thought, could fail to be impressed very much indeed by the admirable address to which they had listened. He did not, unfortunately, hear that portion about sanitation, but he heard the remainder, including a very wide, very able review, and a striking retrospect of canal engineering all over the world. He was also struck with the very thorough and complete manner in which the other

branches of the various subjects were treated, showing not only the studiousness of close reading, but intimate acquaintance with the subjects referred to, and especially in the departments in which they were more particularly interested. They were expecting a great deal from Mr. Richardson, and he with great pleasure congratulated him upon being well enough to undertake the duties of the ensuing year. They had a genuine interest in his well-being and the degree of health to which he had now attained. He hoped he would be spared, and he also hoped that the Institution would receive the stimulus of another address of equal merit. He (Mr. Price) felt that the Institution had attained to a position which might very fairly entitle it to rank alongside of any of the kindred institutions of the country of older life. Their President's ability in the treatment of his subjects warranted their being proud of him, and he felt more satisfied than ever in the future of this Institution. He by no means wished to hint that the earlier Presidents had in any degree failed, but he earnestly joined with Mr. Boyd in his admirable remarks as to the progressive and ascending character and tone of the meeting that night and the address. He had great pleasure in adding his testimony to the high appreciation with which they had listened to the address.

Mr. THEODORE DOXFORD had very great pleasure in indorsing what had been said by the three gentlemen who had already spoken. One reason for his hanging back was that he did not wish that the speaking should be entirely in the hands of Presidents. One advantage, however, they might have in speaking was that they had had the experience of preparing addresses, and they therefore understood the difficulties and labour entailed in such an address as they had heard read that night, and perhaps appreciated it more than those who had not had that experience. After the remarks which had fallen from the previous speakers he did not think it was necessary for him to say more than that he entirely agreed with all that had been said, and he thought this Institution was to be greatly congratulated upon having so able a President for the ensuing year.

The resolution was carried by acclamation.

The PRESIDENT thanked them very much for the kind way in which they had received his address. On the subject of geometry he would like specially to acknowledge the useful information received from Sir Robert Ball, the gifted Irish astronomer, who had formerly lectured in that room, and would refer to Sir Robert's interesting paper on "Screws," read before the British Association, which he would be glad to lend to any one

interested. In regard to M. de Ferranti's electric main shown on the table, he believed that the current passed in the centre copper tube and the outer was for the return current. It was due to this, he believed, that there was no disturbance to the post office or telephone wires. He again wished to thank them. The next meeting would be held in Sunderland on the 21st November, when a paper would be read by Mr. W. R. Cummins on "Increased Boiler Pressure and Increased Piston Speed for Marine Engines."

The meeting then dissolved.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890–91.

PROCEEDINGS.

SECOND GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE SUBSCRIPTION LITERARY SOCIETY, SUNDERLAND, ON FRIDAY EVENING, NOVEMBER 21ST, 1890.

WIGHAM RICHARDSON, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Newcastle-on-Tyne, on October 13th, which were approved by the members present and signed by the President.

The ballot for new members having been taken, the President appointed Messrs. H. Macoll and G. W. Sivewight to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Blackie, Thomas Reid, E. Surveyor to Lloyd's Register of Shipping, Lloyd's Register of Shipping, West Hartlepool.

Charlton, Thomas, Chief Engineer, Earl Fitzwilliam's Yacht, The Cedars, Millhill, West Cowes, Isle of Wight.

Consiglio, Luigi, Naval Architect, c/o Messrs. Hawthorn, Leslie, & Co., Hebburn-on-Tyne.

De-Rusett, Edwin W., Shipbuilder, Warden House, Percy Park Road, Tynemouth.

Hammar, Hugo, Ship Draughtsman, c/o Harrison Loring, Esq., South Boston, Mass., U.S.A.

Henderson, A. M., Works Manager, Central Marine Engine Works, West Hartlepool, Greatham Terrace, West Hartlepool.

Kitching, J. F., Superintendent Engineer to Messrs. R. Irvine & Co., West Hartlepool, Hart Road, West Hartlepool.

Nastoupil, John, Chief Engineer, Austro-Hungarian Navy, 34, Jesmond Road, Newcastle-on-Tyne.

Richardson, Philip Wigham, Shipbuilder, Neptune Works, Walker-on-Tyne.

Thomson, James, Jun., M.A., Civil Engineer, c/o Messrs. Sir W. G. Armstrong, Mitchell, & Co., Ordnance Works, Elswick, Newcastle-on-Tyne.

ASSOCIATES.

Nicholson, John, Marine Superintendent. West View House, South Shields.

Rickinson, John, Shipowner, 9, Church Street, West Hartlepool.

Watson, Thomas W., Marine Superintendent to Messrs. R. Shadford & Co., Sunderland, Gisburn House, Hartlepool.

GRADUATES.

Barbour, John, E. Apprentice, Messrs. North Eastern Marine Engineering Company, Limited, Wallsend, 14, Eslington Terrace, Newcastle-on-Tyne.

Cooper, William, Jun., Engineer, Messrs. J. Smith & Sons, 11, Ridley Place, Newcastle-on-Tyne.

Cowan, David, Ship Draughtsman Apprentice, Messrs. Palmer's Iron and Shipbuilding Co., Jarrow-on-Tyne, 22, Clarendon Terrace, South Shields.

Elder, Edward, Ship Draughtsman, Messrs. Palmer's Iron and Shipbuilding Co., Jarrow, Loudon House, Jarrow-on-Tyne.

Hewitt, John, Ship Draughtsman Apprentice, Messrs. Palmer's Iron and Shipbuilding Co., Jarrow, 29, Holly Street, Jarrow-on-Tyne.

Macmillan, Alexander Stuart, Messrs. Hawthorn, Leslie, & Co., St. Peter's, c/o Messrs. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne.

Phillips, Grafton, E. Apprentice, Messrs. Hawthorn, Leslie, & Co., St. Peter's, c/o Messrs. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne.

Swan, Charles Sheriton, Apprentice Shipbuilder, Messrs. C. S. Swan & Hunter, 29, Percy Gardens, Tynemouth.

Withy, Frederick, Ship Draughtsman, Messrs. J. L. Thompson, North Sands, Sunderland, 14, St. George's Terrace, Sunderland.

Youl, James Arndell, Ship Draughtsman Apprentice, Messrs. Palmer's Works, Jarrow, Sydenham Terrace, Newcastle-on-Tyne.

THE CHAIR OF ENGINEERING, AND THE GRADUATES' MEETINGS.

The PRESIDENT said he was disposed to make a few remarks about the Chair of Engineering in the Durham College of Science, the appointment of which was to be placed in the hands of this Institution. The Chancellor of the Exchequer had placed sums at the disposal of the various County Councils for the promotion of technical education. There were no less than four County Councils having under their disposal funds that might go to aid the Durham College of Science. There was first the County Council of Sunderland. They all knew the enterprise of their friends of Sunderland and the desire manifested for the well-being and progress of the inhabitants. There was the County Council of Newcastle-upon-Tyne, the County Council of Durham, and the County Council of Northumberland. He would now ask Mr. Macoll to make some remarks upon this and the Graduates' meetings.

Mr. H. MACOLL observed first of all, that as regarded the Chair of Marine Engineering and Naval Architecture, so far they had met with moderate success in endeavouring to raise a fund. The idea at first was to raise a sum which, capitalized and invested, would give a sufficient inducement to talented gentlemen to occupy the chair; but, as business was not very bright in the way of profit making at present, they had had to climb down from that position and endeavour to obtain sufficient funds to enable them to secure an appointment for about three years. They thought it would not be practicable to get a good man to undertake the duties of the chair for less than that time, and if the scheme was a success during the three years, there would be reasonable grounds in asking more money to establish the chair in a more permanent and satisfactory manner. So far, he thought they might say they had got fully the half of the sum necessary. It had occurred to several of the members that as the County Councils had the administering of a large sum of money, and that as this chair was a desirable object and one well worthy to be supported out of the public funds to a certain extent, there might be a good claim made on the Councils of the district to contribute towards this chair. It is more of a national concern than local, and people in the Hartlepools and round about might not feel so willing to contribute to a chair in Newcastle as not being so accessible to their friends.

On the other hand, as regarded the actual amounts they had had much more success in obtaining contributions from Hartlepool and that district than from either the Tyne or the Wear, which said a good deal for the public spirit of these gentlemen. It ought to strengthen the hands of the Council of the Institution in dealing with this matter. It was also intended to approach the County Councils as soon as possible, and ascertain their views in the matter. As regarded the Graduates, the second meeting of this session was held last Wednesday in Newcastle, when the President of the section, Mr. Frank T. Marshall, gave a very interesting and useful address on Forced Draught. Now there was a great want of a little more animation in this Graduate section. The numbers were rather small, and it was very desirable that the attendance should be augmented very considerably. In a large engineering and shipbuilding district like this, more than a dozen and a half young men in these professions might be expected to meet in this way for mutual improvement, which would be secured by reading papers and discussing matters connected with their business. The Council of the Institution having supplied a room and given them the use of the place, they would like to see more members coming forward, especially as there was now a fund at the disposal of the Council for the granting of awards to the authors of the best papers contributed during each session. It only lay with the Graduates themselves to come forward in larger numbers. The Committee of the Graduate section had made arrangements for excursions to several works in the district, a feature not only interesting, but very useful.

Mr. ROBERT THOMPSON endorsed what Mr. Macoll had said, and stated that the Committee in the district had been moving in the matter of support for the Chair of Engineering. Something like £3,000 would be apportioned to the Sunderland Council for the purpose of technical education, and it struck them that shipbuilding being by far the largest interest in the district, they might reasonably approach the Council with the idea of getting it, if possible, to apportion a part of this sum to the founding of the chair in question. He was quite sure that so far as the district was concerned, the proceedings of their Institution would compare favourably with the Clyde or any other, their papers and discussions being creditable to the Institution, and a very great benefit to the district. He thought under the favourable circumstances in which they were getting this money they had a fair claim to some portion of it, because technical education was what was wanted, and if they could found a Chair of Engineering in the Durham College—for although in

Newcastle it was the Durham College—he was quite sure it would further the interests of this district very materially. The College and Principal Garnett offered every facility, and went as far as possible in the way of lightening the fees of the students. He (Mr. Thompson) was quite sure if they could carry this scheme out it would be an immense benefit to the district. So far as Sunderland was concerned, they were determined to push the project as strongly as they could to obtain the monetary aid and establish the chair. As to the Graduates, he was rather surprised at the lack of interest amongst these young members, because it could not be said that they had no time. There was abundance of time for recreation. It was well enough to have physical exercise, but the improvement of the mind was of the first importance. In his young days it was pretty hard work to acquire information; now the facilities were much enlarged, and it depended upon themselves what they would make of the future, and how they would equip themselves to take their places. What had been said that night would, he hoped, bear fruit; and that the young men of the Institution, taking all the advantages for self-improvement, would work so as to better their own position, and at the same time improve the position of the district.

THE NEW SUB-COMMITTEE AT LLOYD'S.

The SECRETARY (Mr. Duckitt) read the following letter, which he thought would be of interest. It was from Mr. Muirhead, Secretary to the General Association of Clyde Shipbuilders and Engineers:—

GLASGOW, 20*th November*, 1890.

J. DUCKITT,—DEAR SIR,—I was duly favoured with your letter of 14th October, kindly informing me that your Institution had nominated Wm. Boyd, Esq.; Francis Carr Marshall, Esq.; Robert Thompson, Esq.; and Henry Withy, Esq., as their representatives. I am glad to say that the Institution of Naval Architects, London, have nominated Sir Edward Harland, Bart., M.P., as representative for Ireland, their other representatives being H. H. Laird, Esq., Liverpool; A. D. Bryce Douglas, Esq., Barrow; and R. Sennet, Esq., London. The Glasgow Institute have nominated Messrs. John Ward, of Messrs. Denny and Brothers, Dumbarton; D. J. Dunlop, Port Glasgow; John Inglis and Dr. A. C. Kirk as their representatives, and as soon as I am informed that these gentleman have accepted their appointments, which I expect will be immediately, I shall forward the completed list to Lloyd's.

Yours truly,

J. MUIRHEAD, *Secretary.*

The SECRETARY read a paper on "Increased Boiler Pressure and Increased Piston Speed for Marine Engines," by Mr. William Russell Cummins.

INCREASED BOILER PRESSURE AND INCREASED PISTON SPEED FOR MARINE ENGINES.

By WILLIAM RUSSELL CUMMINS.

[Read before the Institution in Sunderland, on November 21st, 1890.]

The object of this paper is to raise a few questions as to the advisability of increasing (1) the working pressure, and (2) the piston speed of marine engines; and to consider what type of engine and boiler would best suit these new conditions. The superiority of the three-crank triple expansion engine over the old two-crank compound is generally attributed to three causes:—First, to increased working pressure giving a greater total temperature range, and allowing of a greater ratio of expansion; secondly, to decrease of temperature range in each cylinder, thus causing less loss from cylinder condensation; and thirdly, to increased piston speed.

To compare the economy of steam of 165 lbs. absolute pressure with steam of 115 lbs. absolute pressure, let it be assumed that we have 1 lb. of dry saturated steam at 115 lbs. absolute pressure. A certain quantity of coal has been expended to produce this lb. of steam; and the first question which arises is—How much coal will be expended to produce 1 lb. of steam at 165 lbs. absolute pressure? The efficiency of the heating surface should be rather less in the case of the higher pressure, as the temperature of the water will be higher. Assuming, however, that the efficiency is not appreciably decreased for the extra rise of temperature (72 degs. Fah.), then for the same amount of coal expended we have—

$$1 \times \frac{\text{Total heat of 1 lb. steam at 115 lbs. pressure}}{\text{Total heat of 1 lb. steam at 165 lbs. pressure}} = \cdot 99305 \text{ lbs. steam at}$$

165 lbs. absolute pressure, to compare with 1 lb. of steam at 115 lbs. absolute pressure.

Next, assume that the steam of 115 lbs. pressure is expanded adiabatically to 8 lbs. absolute, and that the steam of 165 lbs. pressure is expanded to 6 lbs. absolute, the back pressure in both cases being 4 lbs.

(using a formula given by Rankine for the amount of liquefaction due to expansive working), we have for the proportion of liquefied water at the end of expansion the expression—

$$1 - \frac{T_2}{H_2}\left(J \text{ hyp. log. } \frac{T_1}{T} + \frac{H_1}{T_1}\right),$$

where T_1 = absolute initial temperature;
T_2 = absolute temperature at end of expansion;
H_1 = latent heat per lb. of initial steam;
H_2 = latent heat per lb. of steam at end of expansion.

Thus, for steam of 115 lbs. absolute pressure, and terminal pressure 8 lbs. absolute—

T_1 = 799·01 degs. Fah.,
T_2 = 644·11 degs. Fah.,
H_1 = 675864 ft. lbs.,
H_2 = 761381 ft. lbs.,

and the proportion of steam liquefied = 14·34 per cent.; so that, at the beginning of expansion, there is 1 lb. of steam at 115 lbs. absolute pressure, and at the end of expansion ·8563 lbs. steam at 8 lbs. absolute pressure and ·1437 lbs. water. For convenience, let it be assumed that this proportion does not vary during the exhaust period. Then, heat received = total heat of 1 lb. steam at 115 lbs. absolute pressure = 1216·974 thermal units. Heat rejected = total heat of ·8563 lbs. steam at 4 lbs. absolute pressure = 993·843 thermal units + heat of ·1437 lbs. water at same temperature = 22·043 thermal units. Total heat rejected = 993·843 + 22·043 = 1015·886 thermal units.

1216·2741 − 1015·886 = 201·088 thermal units utilised.

For steam of 165 lbs. absolute pressure, and terminal pressure 6 lbs. absolute—

T_1 = 826·94 degs. Fah.,
T_2 = 631·32 degs. Fah.,
H_1 = 660110 ft. lbs.,
H_2 = 768333 ft. lbs.,

and the proportion of steam liquefied at the end of expansion = 17·29 per cent.; so that, at the beginning of expansion, we have ·99305 lbs. steam at 165 lbs. absolute pressure, and at the end of the expansion ·82136 lbs. steam and ·17169 lbs. water at 6 lbs. absolute pressure. Then, heat received = total heat of ·99305 lbs. steam at 165 lbs. absolute pressure = 1216·974 thermal units. Heat rejected = total heat of ·82136 lbs. steam at 4 lbs. absolute pressure = 953·29 thermal units + heat of

·17169 lbs. water at same temperature = 26·339 thermal units. Total heat rejected = 953·29 + 26·339 = 979·629 thermal units.

1216·974 — 979·629 = 237·345 thermal units utilised.

Heat utilised with steam of 115 lbs. absolute pressure = 201·088 thermal units.

Heat utilised with steam of 165 lbs. absolute pressure = 237·345 thermal units.

$\frac{237·345 - 201·088}{201·088} \times 100 = 18$ per cent. economy of 165 lbs. steam over 115 lbs. steam.

Passing on now to the second alleged cause of the economy of the triple expansion engine, the general effect of cylinder condensation is to cause a lowering of temperature at the beginning of the stroke and a raising of temperature at the end of the stroke, as indicated by the heat diagram, Fig. 1, Plate I. A B C D E represents the heat diagram of an engine in which there is no initial condensation, B C being an adiabatic curve produced down to the zero of temperature. The heat diagram of an engine in which initial condensation takes place is indicated by F G H D E, A B G F representing the amount of heat stored up in the walls of the cylinder at the point of cut-off. By the principle of work the area under the curve A B C is equal to the area under the curve F G H, so that if the process were carried down to the zero of temperature there would be no loss from cylinder condensation; but as in practice the process must be stopped at a point J, say, the difference between the areas A B G F and G J K will represent the amount of loss due to condensation. Or suppose 2 lbs. of steam are admitted to a cylinder at 100 lbs. pressure, and that 1 lb. is condensed on the cylinder surfaces, then let the steam be expanded down to 50 lbs. pressure, assuming that all the condensed steam is by that time re-evaporated. Divide the period of expansion into any number of stages. At the beginning of expansion there is 1 lb. of steam at 100 lbs. pressure, and by expanding it down to 50 lbs., a certain amount of energy can be extracted to do external work.

At the end of the first stage a certain amount of the condensed steam will have been evaporated by the heat contained in the cylinder walls, and will be available for doing work. It is, however, at a lower temperature than the initial steam, and therefore has less potential energy. By dividing the period of expansion into a sufficient number of stages, and adding up the available energy of each portion of steam as it gets

re-evaporated, and comparing the total thus obtained with the available energy of 2 lbs. of steam for the total temperature, an idea of the loss due to condensation between the assumed limits may be obtained.

Condensation in the cylinder may be prevented by means of a steam jacket, but no economy can be effected thereby. Suppose a certain quantity of steam at 100 lbs. pressure, containing 200 thermal units, be admitted to an unjacketed cylinder, and assume that the walls of the cylinder absorb 100 thermal units, a certain amount of energy will be extracted from the remaining 100 thermal units, and also a certain portion of the heat stored up in the cylinder walls, will, as expansion proceeds, become available for doing work.

Next, suppose the cylinder to be jacketed with steam of 100 lbs. pressure. If no steam be condensed on entering the cylinder, it follows that the walls must have absorbed 100 thermal units from the steam in the jacket.

In the one case 200 thermal units have been put into the cylinder and 100 thermal units into the jacket, up to the point of cut-off; and in the other case (to secure equal conditions, viz., 200 thermal units at initial temperature at point of cut off), 300 thermal units are put into the cylinder direct, the result being the same in both cases. Thus no economy can result from the use of a jacket, but it may be very convenient in cases of great ratios of expansion to prevent flooding of the cylinder. It must not be forgotten that the jacket is also transmitting heat to the steam and water in the cylinder during the period of expansion. If the steam in the cylinder has no water mixed with it at the beginning of the expansion the jacket will prevent liquefaction due to expansion, or it may possibly superheat the steam. This transmission of heat from a higher to a lower temperature involves a loss. Suppose, for example, that 100 thermal units were transmitted to the steam in the cylinder during the period of expansion, by jacket steam. The amount of loss in this case is measured by the difference in the efficiency of 100 thermal units at 100 lbs. pressure and 100 thermal units at some temperature *lower* than this. This argument also applies to all cases where steam of a higher pressure gives up heat to steam of a lower pressure, as happens between the steam and exhaust side of a slide valve, and also where exhaust steam is in contact with the cylinder walls.

The next question which arises is, what is the action of condensation as effected by division of temperature range by passing the steam successively through two or more cylinders? For the means of comparison let us take as examples a simple engine and a compound; the low pres-

sure cylinder of the compound being of the same capacity as the single cylinder of the simple engine. For convenience let it be assumed that in the case of the compound engine the same amount of steam is condensed in each cylinder. Suppose, for example, that 4 lbs. of steam are admitted to the high pressure cylinder, of which 1 lb. is condensed up to the point of cut-off. Assume that this pound of water will be re-evaporated by the end of the stroke. The steam is then admitted to the low pressure cylinder, and 1 lb. of it condensed up to the point of cut-off, the water, as before, being re-evaporated by the end of the stroke.

This process can be represented by a diagram (see Fig. 2, Plate I.). Let horizontal ordinates represent weights of steam, and vertical ordinates temperatures. A C will represent the 3 lbs. of steam present at point of cut-off in the high pressure cylinder. For the sake of simplicity let it be assumed that the re-evaporation of the condensed steam follows the line C F, so that in the high pressure cylinder the amount of loss may be represented by the triangle C B F, and similarly in the low pressure cylinder by the triangle E F J, so that the total loss may be indicated by the rectangle E F J H. Now, what will happen in the case of the simple engine? The surface for condensation will be, roughly, about one-fourth less than before, owing to the earlier cut-off; but it is raised through twice the temperature.

Under these conditions it is probable that more than 1 lb. of steam will be condensed, say, for example, an amount equal to K B. Then the loss will be represented by the triangle K J B, and the double cylinder will be more economical by the value of the triangle K J C. Of course there are no grounds for assuming that the re-evaporation takes place as indicated here, but it will serve to show why an economy should result from divided temperature range.

As regards the third cause of the economy of the triple expansion engine, viz., increased piston speed, the advantage of this is evident. Take the case of two identical engines, one, however, running at twice the number of revolutions of the other. The amount of steam condensed will be the same in both engines, but the proportion of steam condensed to steam passing through the engine (which measures the loss) will be very much less in the fast running engine. Thus an increase of revolutions should always tend towards economy of steam. The increase of piston speed in the case of the triple expansion engine compared with the compound has not, however, been very great. As pointed out before, the economy of steam of 150 lbs. pressure over steam of 100 lbs. pressure is 18 per cent., assuming the boiler efficiency to be the same in both cases.

The generally admitted economy of the triple expansion engine is 20 per cent., from which it would appear that the economy has been mainly due to the increase of the working pressure and increased expansions, and that the effect of the decreased temperature range in the cylinders and increased piston speed has in this case been inappreciable. Using the formula as given before for calculating the efficiency of steam of 220 lbs. absolute pressure expanded to 5 lbs. absolute, we have—

$T_1 = 851{\cdot}04$ degs. Fah.,
$T_2 = 623{\cdot}53$ degs. Fah.,
$H_1 = 646423$ ft. lbs.,
$H_2 = 772561$ ft. lbs.,

and the proportion of steam liquefied at the end of the expansion = 19·32 per cent. The weight of initial steam—

$$= 1 \times \frac{\text{total heat of steam at 115 lbs. absolute pressure}}{\text{total heat of steam at 220 lbs. absolute pressure}} = {\cdot}98713 \text{ lbs.};$$

so that, at the beginning of expansion, we have ·98713 lbs. steam at 220 lbs. absolute pressure, and at the end of expansion ·79642 lbs. steam at 5 lbs. absolute pressure and ·19071 lbs. water. Heat received = total heat of ·98713 lbs. steam at 220 lbs. absolute pressure = 1216·974 thermal units. Heat rejected = total heat of ·79642 lbs. steam at 4 lbs. absolute = 924·344 thermal units + heat of ·19071 lbs. water at same temperature = 29·254 thermal units. 924·344 + 29·254 = 953·598 thermal units rejected.

1216·974 — 953·598 = 263·376 thermal units utilised.

Thermal units utilised by steam of 165 lbs. absolute pressure = 237·345.

$$\frac{263{\cdot}376 - 237{\cdot}345}{237{\cdot}345} \times 100 = 10 \text{ per cent.}$$

economy of steam of 220 lbs. absolute over steam of 165 lbs. absolute pressure.

For steam of 265 lbs. absolute pressure expanded to 5 lbs. absolute—

$T_1 = 867{\cdot}04$ degs. Fah.
$T_2 = 623{\cdot}53$ degs. Fah.
$H_1 = 637267$ ft. lbs.
$H_2 = 772561$ ft. lbs.

The proportion of steam liquefied at the end of expansion=20·17 per cent. Weight of initial steam—

$$= 1 \times \frac{\text{total heat of 1 lb. steam at 115 lbs. absolute pressure}}{\text{total heat of 1 lb. steam at 265 lbs. absolute pressure}} = {\cdot}98323 \text{ lbs.}$$

am at 265 lbs.; so that, at the beginning of expansion, we have ·98323

lbs. steam at 265 lbs. absolute pressure, and at the end ·78492 lbs. steam at 5 lbs., and ·19831 lbs. water. Heat received = total heat of ·98323 lbs. steam at 265 lbs. absolute pressure = 1216·974 thermal units. Heat rejected = total heat of ·78492 lbs. steam at 4 lbs. = 910·997 thermal units + heat of ·19831 lbs. water at same temperature = 30·419 thermal units, 910·997 + 30·419 = 941·417 thermal units rejected.

$$1216{\cdot}974 - 941{\cdot}417 = 275{\cdot}557 \text{ thermal units utilised.}$$

Thermal units utilised by steam of 165 lbs. pressure = 237·345.

$$\frac{275{\cdot}557 - 237{\cdot}345}{237{\cdot}345} \times 100 = 16 \text{ per cent.}$$

economy of steam of 265 lbs. absolute pressure over steam of 165 lbs. absolute pressure.

If, taking into consideration the gain of 16 per cent. in steam economy and the admitted economy of high piston speed, it is deemed advisable to increase the boiler pressure to 250 lbs. per square inch, and also to increase the piston speed, the next question to be decided is—What type of engine will best suit these new conditions?

There are several types of engine which could be adopted, viz., two-crank four cylinder tandem, two-crank three cylinder tandem, three-crank three cylinder, and four-crank four cylinder. The two first are not at all suitable for high speeds, so that the choice lies between the two last.

In the first place, the four cylinder type has an advantage over the three cylinder type in the matter of steam distribution, as the cut-off must be much earlier in the three cylinder engine. This early cut-off, besides making the engines unhandy, only allows of a small valve opening, thus necessitating a large travel to get the requisite steam opening. The travel of the valves is limited by the length of the cylinders, the limit being often reached with engines of the present type.

As regards the maximum piston speed at which the two types could be run, the three cylinder engine would have a greater initial pressure to counterbalance the inertia of the moving parts; but on the other hand, the four cylinder engine having less initial pressure, would have less weight of moving parts. As, however, the weight of the moving parts is proportional to the initial load, the maximum piston speed will be the same for both types Another advantage of the four-crank type is, that only two sets of valve gear are required; so that, on the whole, it would appear that the four-crank four cylinder type of engine will be the most suitable for the new conditions.

There are two important limits to the number of revolutions at which an engine can be run. The first limit is reached when the pressure per square inch of piston required to accelerate the reciprocating parts at the beginning of the stroke is equal to the pressure of the initial steam.

"Pounding" at the end of the stroke happens when the centrifugal force of the reciprocating parts is greater than the force exerted by the steam of initial pressure on the other side of the piston, so that at the end of the stroke there is an unbalanced force causing a shock, which is immediately followed by another shock produced by the steam of initial pressure taking up the "play" of the brasses. When an engine is working smoothly, the pressure of the steam being compressed behind the piston, assisted by the "lead," is enough to overcome the inertia of the reciprocating parts before the crank is on its centre, so that there is no jar at the end of the stroke.

The second limit to the number of revolutions is imposed by the "swing" of the connecting rod. At or about half stroke the transverse motion of the connecting rod is changed in direction, so that at that point the connecting rod will exert a force on the cross-head, tending, on the upstroke, to increase the pressure on the guide, and on the down-stroke to decrease the pressure on the guide. On the upstroke this increase of pressure can be taken up by an increase of guide surface. On the down-stroke, however, the connecting rod decreases the pressure on the guide, and if the revolutions were sufficiently high, the slipper would leave the "ahead" guide and come up against the "astern" guide. Under these conditions it is very probable the piston rod would heat, so that the limit of revolutions would be reached when the force exerted by the connecting rod on the cross-head was equal to the pressure on the guide.

We now pass on to the design of the cylinder ratios, etc., for the new pressure, after which the revolutions may be fixed.

The usual method of designing cylinder ratios, points of cut-off, etc., is to arrange that the indicated horse-power developed in each cylinder should be the same. The indicated horse-power of each cylinder being the same, the initial loads may or may not be equal (in most cases they are not equal), and since the piston rods and connecting rods are always in duplicate, it follows that they must be designed to transmit the highest of the initial loads.

The writer ventures to suggest that cylinder ratios, etc., should be designed so as to obtain equal initial loads in each cylinder. By this

method the greatest economy is obtained in the weight of the reciprocating parts, a very important point in high speed engines. The method used in the present instance has been to combine actual diagrams from a triple expansion engine of 160 lbs. boiler pressure (see Fig. 3, Plate I.).

Since the diagram is for comparative purposes only, the cards have been set off without taking account of clearance and compression, and the steam curve continued up to 265 lbs. pressure, has, for the sake of simplicity, been plotted as a constant weight curve. The back pressure has been taken at $3\frac{1}{2}$ lbs. on the low pressure piston. The ratios for the triple have been so arranged as to give equal initial loads with a minimum of "drop" between the cylinders.

It will be seen from the diagram that there is a considerable "drop" between the first and second cylinders. This is owing to the necessity of keeping the first cylinder small, so that the cut-off need not be too early. The quadruple has been arranged on the same method. It will be noticed that the drop between the cylinders is very small.

The loss from drop is represented very nearly by the area of the triangular piece A B C. A certain quantity of heat is, however, regained, as the steam on expanding into the receiver, without doing work, will, if dry, become superheated, or if it contains suspended water, a portion of it will be evaporated, and become available for doing work in the next cylinder, from which it will be seen that if a drop cannot be avoided, it will be best to arrange it at the higher pressure, so that the greatest amount of heat may be regained, as the farther the expansion is carried the greater the amount of heat regained. It may be argued that with large "drops" smaller cylinders may be used, consequently the engines would weigh and cost less. The most economical amount of drop will be reached when the percentage of loss caused by any further "drop" is greater than the percentage of weight saved by using a smaller cylinder.

These same considerations apply to the most economical number of expansions of the steam. By increasing the number of expansions more work is obtained from the steam; but at the same time the engines will be larger, and the limit to the number of expansions will be reached when the percentage of gain due to any further increase of expansion is less than the percentage of weight added to the engines.

Coming back to the diagram, it will be seen that the cylinder ratios of the triple are 1 : 2·04 : 6·54, and for the quadruple—

1 : 2·08 : 4·46 : 10·47.

It will be noted that, according to the diagram, the volume of the low pressure cylinder is the same for both engines. It is probable that

actually the low pressure cylinder of the quadruple will have a greater volume; this, however, will not introduce any appreciable error into the calculations.

For facility of comparison, let us take as an example a triple expansion engine of $\frac{28'' \times 40'' \times 71''}{48''} \times 150$ lbs. pressure; revolutions = 65 = "normal" revolutions of the Institution's Rule, and arrange the corresponding quadruple to develop the same horse-power. The first point is to decide upon the stroke of the quadruple. It will be of advantage to keep the stroke as long as possible, as the longer the stroke the greater the piston speed with "normal" revolutions; besides which long strokes and consequently small diameters of cylinders will save space longitudinally, the height of the engines being in merchant vessels generally of little consequence. Let the stroke of the quadruple, then, be taken at 48 inches, same as the triple. To determine the number of revolutions, let it be assumed that the engines can be run safely and smoothly when the initial pressure is equal to the pressure required to absorb the inertia of the reciprocating parts at the end of the stroke, and when there is a margin of pressure, always keeping the slipper on its guide.

Let w = weight of reciprocating parts per square inch of piston.

n = number of revolutions per minute.

r = radius of crank in feet.

c = length of connecting rod in feet.

The weight of the reciprocating parts per square inch of piston will probably be—

For 1st cylinder = 7·5 lbs. per square inch.
„ 2nd „ = 4·0 „ „
„ 3rd „ = 2·5 „ „
„ 4th „ = 1·8 „ „

The pressure per square inch of piston required to accelerate the reciprocating parts at the beginning of the stroke—

$$p = \cdot 00034 \times w \times n^2 \times r \times \frac{C + r}{C} - w \text{ for top centre.}$$

$$p = \cdot 00034 \times w \times n^2 \times r \times \frac{C - r}{C} + w \text{ for bottom centre.}$$

In our case—

p = 146 lbs. per square inch for 1st cylinder.
= 70 „ „ „ 2nd „
= 32·5 „ „ „ 3rd „
= 14·0 „ „ „ 4th „

Limit of revolutions—

1st cylinder	top	156	revolutions.
	bottom	188	,,
2nd cylinder	top	148	,,
	bottom	178	,,
3rd cylinder	top	104	,,
	bottom	151	,,
4th cylinder	top	101	,,
	bottom	115	,,

This practically limits the revolutions to 100 per minute.

No account has yet been taken of the inertia of the moving parts of the pumps. If the pumps are worked off the fourth cylinder, the revolutions must be reduced, if the pressures in the pumps themselves are not sufficient to overcome the inertia of the moving parts at the beginning of the stroke.

For the second cylinder—

$$p = 70 = \cdot00034 \times w \times 100^2 \times 2 \times \frac{10\cdot5}{8\cdot5} - 4.$$

$$w = \frac{74 \times 8\cdot5}{\cdot00034 \times 100^2 \times 2 \times 10\cdot5} = 8\cdot8 \text{ lbs. per square inch of piston.}$$

Weight of piston, connecting rods, etc. = 4 lbs. per square inch of piston; so that the steam in the second cylinder would balance 8·8 — 4·0 = 4·8 lbs. of pump gear per square inch of second cylinder = ·95 lbs. per square inch of fourth cylinder. The actual unbalanced inertia will probably not be more than this, so that the engines can still be run at 100 revolutions if the pumps are driven from the second cylinder.

We have next to consider the other limit of revolutions—viz., the momentum due to the transverse motion of the connecting rod. This has been estimated in the following manner:—The path described by the centre of gravity of the connecting rod being traced out, an arc of a circle is found which will coincide as nearly as possible with the curve at half stroke. The centre of gravity of the rod is assumed to be rotating on the radius thus found.

This is perhaps not a strictly accurate solution of the problem, but will be sufficiently near for the present purpose.

In the case under consideration the weight of the connecting rod proportioned for a 71 inch cylinder = 2100 lbs.; length = 8 ft. 6 in.; centre of gravity, 43 in. from bottom end; radius of arc coinciding with path described by centre of gravity at half stroke = 3·6 ft.; so that the centrifugal force exerted by the rod will be—

$$\cdot00034 \times 2100 \times 100^2 \times 3\cdot6 = 25700 \text{ lbs.}$$

This is equivalent to 10400 lbs. acting at the cross-head.

The pressure on the guides

$$= \frac{\text{Area } 71'' \times 14 \times 2}{8{\cdot}5} = 13000 \text{ lbs.};$$

so that at 100 revolutions there is still a margin of 2600 lbs. to keep the shoe on the guide.

Assuming that by the increased working pressure and increased piston speed an economy of, say, 10 per cent. can be effected, the size of the low pressure cylinder of the quadruple to develop the same indicated horse-power as the triple we have taken as an example, will be—

$$\frac{\text{Area } 71'' \times {\cdot}9 \times 65}{100} = 2316 \text{ square inches} = 55 \text{ inches diameter.}$$

The cylinder ratios, as determined before by the diagram, Fig. 3, Plate I., are 1 : 2·08 : 4·46 : 10·47, so that the quadruple engines will be—

$$\frac{17'' \times 24\tfrac{1}{2}'' \times 36'' \times 55''}{48''} \times 250 \text{ lbs. boiler pressure.}$$

Revolutions per minute = 100.

The size of the triple engine which it is to replace being—

$$\frac{28'' \times 40'' \times 71''}{48''} \times 150 \text{ lbs. pressure.}$$

Revolutions per minute, 65.

The writer would suggest that separate steam and exhaust valves, of the piston type, be adopted, for two reasons: first, because by these means the steam chests can be so arranged that steam of higher pressure does not transmit any of its heat to steam of lower pressure. If, as pointed out before, a certain number of thermal units at a high temperature are more valuable than the same number of thermal units at a lower temperature, an economy should result from the proposed arrangement. The second advantage of separate valves is, that they may be made multiple ported, thus economising weight and space occupied.

Only two sets of valve gear will be required to work all the valves, and the sequence of cranks should be so arranged that the crank of the first cylinder is at right angles to the crank of the second, and so on all through. This is in order to keep the exhaust line parallel with the atmospheric line. With the cranks opposite one another, the exhaust line, at the ends of the stroke, will be below the mean exhaust line, with the result that the initial load will be increased by that amount.

To sum up, the writer has endeavoured to show that the economy of the three-crank triple expansion over the two-crank compound has been mainly due to the increase of boiler pressure, and, to a small extent, to

the increase of piston speed. That by increasing the boiler pressure to 250 lbs. per square inch a steam economy of, say, 15 per cent. can be obtained over the present three-crank triple. That an increase of piston speed besides increasing the economy of steam, will also increase the weight economy, so that the piston speed should be increased up to the limits set down in the paper. That the best type of engine to use this higher pressure, and best adapted to run at a high speed, is the four-crank four cylinder engine, with unjacketed cylinders and separate steam and exhaust valves.

Passing on to the question of the type of boiler to be adopted, the writer is of opinion that a considerable departure from the present design of boiler is necessary, in order to make a satisfactory structure for 250 lbs. pressure. With this pressure difficulties will arise with the furnaces, and the flat sides of the combustion chambers. To get over these difficulties the writer proposes to put the furnaces and combustion chambers outside the boiler altogether. The boiler then becomes a simple cylinder, the tubes running from end to end. As shown in the drawing (Plates II. and III.), the boilers are arranged back to back, with the combustion chambers between them. The furnaces and combustion chamber may be of cast or wrought iron, lined with fire-brick. In order to keep down the grate surface, and thus economise space athwartships, it will be of advantage to use forced draught, and all the air on its way to the furnaces is made to pass over the top and sides of the combustion chamber, thus reducing to a minimum any loss from radiation.

The advantages of a boiler of this type are obvious. It is perfectly suitable for a high pressure. There will be no straining from unequal temperatures. The cost of manufacture will be considerably less than that of the present type of boiler. For the same heating surface the space occupied is less ; the boiler shown on Plates II. and III. is 10 feet 6 inches diameter, and contains the same heating surface as a boiler of the present type 13 feet 6 inches diameter, the lengths in both cases being the same.

DISCUSSION.

Mr. E. HALL-BROWN opened the discussion. Having called the attention of the meeting to the following table :—

MARINE ENGINE TRIALS BY THE INSTITUTE OF MECHANICAL ENGINEERS.

Name of Ship.	S.S. "Meteor."	"Fusi Yama."	"Colchester."
Kind of engine	Triple.	Compound.	Compound.
Feed water not accounted for by diagrams, principally initial condensation	H.P. 22·9 per cent. I.P. 19·8 „ L.P. 24·7 „	H.P. 16·9 per cent. ..... L.P. 29·2 per cent.	H.P. 28 per cent. ..... L.P. 47·3 per cent.
Total water used per I.H.P. per hour	14·98 lbs.	21·17 lbs.	21·73 lbs.
Ratio of heat turned into work to total heat absorbed by feed water	16·1 per cent.	11·25 per cent.	10·7 per cent.
Mean boiler pressure ...	145·2 lbs.	56·84 lbs.	80·5 lbs.
Mean revolutions per min....	71·78	55·54	86 and 87·1

NOTES.—The cylinders of the "Meteor" were jacketed on the barrels only. The cylinders of the "Fusi Yama" and "Colchester" were unjacketed. The "Colchester" is a twin screw steamer, and the revolutions given are for the two engines.

He then proceeded to say that he thought that they must all agree that the paper they had just heard read exhibited considerable ingenuity, at the same time he was sorry to say he could not agree with very many of the results obtained. In the first place, the formula which was given merely represented one-half of the truth, viz., the water condensed during adiabatic expansion in a steam engine. The writer gave the formula as representing the liquefaction during expansion, but the amount of liquefaction during admission, or, as it was usually termed, the initial condensation was entirely left out of the question. Now he (Mr. Hall-Brown) thought that of the two probably the initial condensation was the more important. He had here put down some results from the Institution of Mechanical Engineers' trials of the "Meteor," "Fusi Yama," and "Colchester." From these figures it would be seen that in the case of the "Meteor" (triple) the amount of water missing at the end of the expansion was only slightly greater than at the beginning, showing that during expansion there had not been much increase in the condensation; at any rate it showed initial condensation to be an important factor, amounting in this case to 22·9 per cent. of the total feed water, while the condensation during expansion, as calculated by the writer, is only

16 per cent. in a triple. In the case of the "Fusi Yama" the initial condensation was 20·9, and the "Colchester" 28 per cent. These figures, 22·9, 20·9, and 28 per cent. were figures entirely left out of the writer's calculations, although they were evidently important factors in the economy of the steam engine. To proceed further, the writer of the paper said that the condensation in the steam cylinders could be lessened to a considerable extent by means of the steam jacket, but no economy whatever could result from this. He quite agreed with the writer that the condensation would be lessened, but very much disagreed with him regarding the economy. He (Mr. Hall-Brown) was perfectly convinced that economy could, and, as a general rule, would, result from the steam jacket, one reason for this was that it cost less to get the cylinder walls dry than would be lost by condensation if the cylinder walls were wet. Dry cast iron did not conduct heat from steam at the same rate as wet cast iron, and the initial condensation in a wet cylinder was very great as compared with the condensation in a dry cylinder. This was illustrated by Mr. Willans in his remarks on the marine engine trials before mentioned. He stated that he had had a steam cylinder which would be usually considered very well drained indeed as the port was at the bottom. This cylinder was totally unjacketed. He found there was a considerable amount of condensation, but by putting a little pipe round the bottom on the inside and admitting steam for five minutes the cylinder was dried and kept dry during the whole trial, and the increase of power from the same quantity of steam was very considerable. He did not remember the figures, but practically the cost was nothing, because the steam was only going through the pipes for a few minutes at the beginning of the trial. It was a steam jacket and increased the duty of the engine very materially, while the steam condensed in it was almost nothing. That showed the steam jacket might produce economy. Still more important, however, there had been a collection of trials published by the Mechanical Engineers, and that report was most instructive. It comprised 43 tests of various engines with and without the jackets in use. Each engine was tried with the jackets working and without, and in some instances the reduction in the consumption of water amounted to 40 per cent. These were facts they must deal with, whatever their opinions might be on the matter. He must say that in reading through this paper he had been rather at a loss to picture the style of engine described. He thought it would have been a great advantage if the writer could have given them a drawing of the engine, because a four cylinder engine, with four cranks, and eight valves, driven by two sets

of valve gear, was difficult to picture in the mind. Another point advocated by the writer was separate steam and exhaust valves. He (Mr. Hall-Brown) thought there could be no doubt that this would be conducive to economy provided the valves were of the right sort, but they could make a very bad engine with separate steam and exhaust valves as well as in any other way. He thought the steam and exhaust valves should not be piston valves, because that type had the inherent defect that the area of the surface of the clearance space was necessarily very large, and to put two piston valves where at present there was one would probably increase the exposed surface by at least 30 per cent., which would be a decided loss, for which he did not think the advantage of having two valves would compensate. With Corliss valves, or even small slide valves, he thought an increase in economy, as the writer said, might be attained. The writer's diagram, from which he deduced the ratio of the cylinders, makes no allowance for any clearance space. He rather thought that took away from any value the diagram might have. He could not see how anyone could deduce the ratio of cylinders without showing the clearance space, for this must have a material effect upon the ratio of the cylinders, even if the compression was so great as to carry the compressed steam up to the pressure of the ingoing steam. He thought the ratio given by this diagram must be taken with hesitation. Still further, when they found the ratio given for the quadruple engine was 10·47, he (Mr. Hall-Brown) thought the writer would require to give clearer reasons for advocating such an extreme ratio before it would be tried with any confidence. The best ratio of each style of engine could only be found by experiments; but from any experience he had had, he thought that the condensation in cylinders having such a ratio as this, especially in an unjacketed engine, would certainly be very great, and the engine would be far from economical.

Mr. T. WESTGARTH took exception to the statement that the best description of engine is a four-crank engine. He thought that a mistake. The benefit of the three-cranks had been so great that before any change came to be thought of some sound reason would have to be given. There had been a great improvement in the life of crank shafts since the three-cranks came into vogue. The three-crank engine is a sweeter working and better working engine than any four-crank, at right angles, as was proposed. He thought the paper was something like a lady's letter, for the best part was in the postscript. The author had left what was the most important matter to the end, that was the boiler.

Great attention is given to the engines, but very little to the boilers. This is so in the designing offices as well as in the practical departments of manufacture, and it is a very great mistake. Referring to the boiler which the author proposed, he thought it would be very much better if they put the fire directly under the boiler instead of casing it in a sort of furnace. He believed that the heat which acted upon the plates of the boiler was much more efficient than any other, and the author seemed to lose direct heating surface in his proposal. It might be said that some dirt and sediment would settle to the bottom, but he had had marine type boilers running from three to four years with the flues carried under the bottom, with no trouble from dirt whatever, and the results most satisfactory. The proposed boiler would, he thought, have a tendency to prime unless more space be left between the tubes for the steam to get away, as the nests of tubes were so deep. He thought the chief difficulty of this boiler would be in the combustion chambers. They all knew something of the troubles being experienced with the tubes in boilers under forced draught, and he was able to give them the result of some actual boilers at work on something like the lines the author proposed. A few years ago he was connected with the building of several boilers at Hull similar to that proposed by the author, except that they were fitted with ordinary furnaces; and it was next to impossible to keep the back ends in order. Mr. Spear, Messrs. Wilson's superintendent, had some of those boilers at work: he had written to ask him for the result, and his reply might be interesting to them. Mr. Spear says:—"We have had two sets of main boilers with combustion chambers similar to the tracing sent, viz., the 'Tasso' and 'Argo.' The 'Sea Horse' also had a similar arrangement. None of these gave satisfaction, the tubes were always leaking and plates cracking, but I think some of it must have been due to bad work, and in 'Tasso' and 'Sea Horse' the furnaces were flanged with a very short curve, and the tubes were close to furnace tops. I see no reason why a combustion chamber such as you show should not be all right, but my own experience has been against them." Then he wrote to Mr. Carson, of Hull, who also has some of the same boilers at sea, and he replied at some length, and gave valuable experiences. He said:—"I have carefully examined the photo you sent, and will give you my candid opinion based on my experience of brick combustion chamber boilers over the last fourteen years. The great trouble I have had, and still have (as I still possess five of these boilers afloat), is the keeping of the tubes and landings of plates at the back end from heavy leaking. I have tried every conceivable way of keeping the flames off the tube ends and landings, have built

protecting bridges, baffle walls, etc., but all to no purpose. We cannot stop the leaks. I have, therefore, done away with all the rubbish at the back ends, and left the whole thingas it was originally; but I have fitted internal heaters and circulators with connections to the feed donkey; and thus with the careful attention of the engineer in the matter of opening only one fire door at a time when firing, putting on the draught plates on furnace bottom, closing dampers when standing instead of opening the furnace doors as is usually done, and also when done with steam, closing all up, letting the fires die out gradually, and the boilers cool gradually down." So they saw it was evident he had very great trouble to get these boilers to stand. It was very easy to give orders as to the working of boilers, but difficult to get them carried out. Then he (Mr. Carson) gave his opinion upon the boiler proposed which was, perhaps, valuable :— "I think you will have trouble with your design of boiler the same as I have had. I almost think you will have some trouble with the brick work on top of the furnaces, especially with the forced draught. I also think the temperature of the escaping gases in the funnel will be very high. Could you not arrange for the gases to pass twice through each nest of tubes instead of once; you would find this very much more economical, and it would make a very compact and symmetrical arrangement, the uptake being in the middle instead of having to be carried over the top of both boilers. The boilers will be cheap to manufacture, will be lighter both in iron and water, and if you can prevent the leakage at the back end ought to be almost everlasting in wear." One other thing he would bring under their notice in discussing boilers of an improved type. His friend, Mr. Carson, had had the courage not only to invent but to put into a ship a new style of boiler. He sent him a drawing, and thought it might be interesting. It was actually at work, and doing very good work. (See Plate IV.) He brought the gases through the lower tubes, and back through the upper rows. He said that with 180 lbs. working pressure the water evaporated is 10·1 lbs. per lb. of coal, burning 20·3 lbs. per square foot of grate, and the coal with quadruple engines 1·21 lbs. per indicated horse-power. These figures seemed rather extreme, but they were the results of careful experiment and actual work.

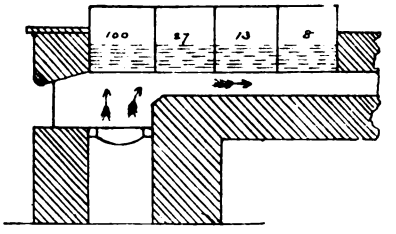
Mr. Robt. Thompson, in regard to the number of revolutions, said the economy of that depended very much upon the form of the ship they had to drive, and that, of course, came back upon the question of propeller. If they were going to run at 100 revolutions, then to get the best result from these revolutions, in designing they had to specially con-

the form of the ship into which they were going to put the machinery.

From his experience there had been a great gain from the triple expansion engine. In this paper credit was given to the boilers, but from his observation much of the gain was from three as compared with two-cranks giving a more regular running engine, and thus more effective power in driving the ship. He liked to see papers of this kind because it brought out discussion, and all discussion tended to do good and to prevent mistakes, and gave them new ideas. What he would like to know was if the quadruple expansion was not actually bringing the engine back to the double-cranked engine, because where the cranks were fitted in the way named in the paper, the direction of the force was the same as in the ordinary double-cranked engine ?

Mr. J. R. FOTHERGILL said he thought this was unquestionably a very able paper, but it was a paper somewhat theoretical in its aspect, and to enter fully upon that side of the question required more time for its consideration than he had been able to give, and thus he did not propose to criticise the various calculations the author had put forth. He (Mr. Fothergill) believed that in the near future they would have the quadruple engine with higher pressures. When the triple expansion was introduced, there were endless predictions as to its failure. Difficulties apprehended in general arrangement of details, difficulties the outcome of pressure and heat, and difficulties in general working. Well, triple expansion with 160 lbs. pressure was an accomplished fact, and all those foretold difficulties had with time gradually disappeared, and he had no reason to doubt but that in a few years the quadruple would prove a practical success. With the introduction of higher pressures he hoped to see a bold advance made, for it appeared to him there must be a material increase in the pressure to give an economy commensurate with the extra capital, outlay, and up-keep. The saving effected by increasing from 80 lbs. in the compound to 165 lbs. in the triple gave, in round figures, 20 per cent. By increasing from 165 lbs. in the triple to 265 lbs. in the quadruple, saving would be, in round figures, 16 per cent., but the 16 per cent. saved would be effected on a less quantity of coal than was the 20 per cent. ; therefore the practical gain due to 265 lbs. pressure as compared with the 165 lbs. over the 80 lbs. would be a material different amount in £ s. d. He was therefore very emphatic, if anything was to be done at all in quadrupling we should have not less than 265 lbs. pressures, and this brought them to that difficult problem—the boiler. Many designs had been conceived, and much ingenuity expended on this subject, and yet the old-fashioned type of boiler at present in use had not been supplanted, and he thought when its many practical advantages were

fully realised it was not difficult to understand why it held its own against all comers, and yet he must confess he thought it would be a difficult problem to continue its use to 265 lbs. pressure. He could not say he favoured the boiler proposed by the writer of this paper. It was a boiler essentially dependent upon tube heating surface, and although the total square feet of heating surface in this boiler might be the same as in the ordinary type of boiler, yet it would not be anything like so effective. Where they got direct impact of flame, *i.e.*, the hot gases or flame striking the plates, more particularly at right angles they got a very much higher evaporative efficiency. Some very instructive experiments had been made to test the relative efficiency of different portions of the boiler. The experiments were conducted by well-known authorities—Messrs. E. Woods, J. Dewrance, C. W. Williams, J. Graham, and others both in this country and in France. Mr. J. Graham carried out a long series of experiments to practically test the action of radiant heat and the direct action of the gases and flame impinging upon the plate. He placed four open, flat-bottom tanks, 12 inches square, in a row as per sketch :—



The grate was 12 inches square direct under the first tank. The first tank showed the direct heating effect of fire ; the second the effect of an equal surface of blaze ; the third and fourth the effect of heated air only. With a moderately strong draught the quantities of water evaporated per hour were proportionally :—

1st tank as	...	...	...	...	100
2nd „	...	...	...	...	27
3rd „	...	...	...	...	13
4rd „	...	...	...	...	8

thus two-thirds of the whole evaporation was effected from the first tank, by the joint action of radiant heat and carried heat, and only a twentieth from the last tank. Mr. Graham then carried out a second series of experiments with three cylinders $\frac{1}{4}$ inch thick, 3 feet diameter, and 3 feet long, open to the atmosphere, which were placed similarly as in the above

sketch. The heating surface of the 1st, 2nd, and 3rd cylinders were 10·53, 14·13, and 14·13 feet respectively. The comparative quantities of water evaporated were :—

1st tank as	...	...	...	...	100
2nd „	...	...	...	...	39·3
3rd „	...	...	...	...	17·1

Here, again, we find the evaporative efficiency of the first boiler exposed to the action of radiant heat is about two-thirds of the whole evaporation. Messrs. Wood and Dewrance carried out a series of experiments with a locomotive boiler in which the tubes were 5½ feet long. The barrel of the boiler was divided into six compartments by vertical diaphragms. The first compartment 6 inches long, and each of the others 12 inches long. It was found that the evaporative efficiency of the first compartment was about the same per square foot as that of the fire box, that of the second compartment about one-third of that value, and that of the remaining compartments very small. The first 6 inches of tubes did more work than the remaining 60 inches. M. Petiet, of the Northern Railway of France, carried out a series of very complete experiments with a locomotive boiler in which the barrel was divided into four sections, each 3 feet in length, and having a length of 3½ inches of tubes attached to the fire box. The results were as follows :—

					Square Feet Heating Surface.		Lbs. Water Evaporated Per Hour.
1st section (fire box and 3½ inches of tubes)					76·43	...	24·5
2nd „	tubes	...	...	...	179	...	8·72
3rd „	„	...	...	...	179	...	4·42
4th „	„	...	...	...	179	...	2·52
5th „	„	...	...	...	179	...	1·68

We thus see that the fire box section evaporated, in round figures, 30 per cent. more water than the tube section, although the area of tube-heating surface was nearly ten times that of the fire box. Mr. C. W. Williams made many experiments with single tubes through a tank divided into compartments. The first compartment was 6 inches long, and the four other compartments each 12 inches long. The comparative quantities evaporated were :—

1st compartment, say	...	..	...	100
2nd „	...	..	...	42·6
3rd „	...	...	...	25·0
4th „	...	...	...	20·0
5th „	...	...	..	16·6

He (Mr. Fothergill) felt he had dwelt at some length on this subject, but he thought they would agree with him that any consideration of the boiler question in the face of a probable endeavour to introduce an entirely new design was a subject of the greatest importance, and he thought he had been able to show conclusively that the boiler of the future would have to be designed to take full advantage of radiant heat and impact of the gases, which he held was not the case with the boiler proposed by the author of this paper. The author alluded to forced draught. He (Mr. Fothergill) was, of course, a strong advocate for forced draught, and he felt certain when it was better understood it would become more general. There was no risk of damage to boilers when using moderate air pressures. If boilers were kept clean and an ashpit W.G. pressure not exceeding $\frac{3}{4}$ inch used, there was no doubt whatever as to the advantage and economy. He agreed with Mr. Hall-Brown, that when the steam jacket was properly applied, and a sufficient staff to give it the necessary attention, it was unquestionably economic; but he held the want of reliable automatic appliances and general attention so far as cargo boats were concerned, more economy would be got out of the steam by putting it into the cylinders.

The PRESIDENT, referring to Mr. Fothergill's sketch on page 66, asked: suppose the first tank was removed entirely and none of the heat taken away by it, did the experiment show how much heat was taken up by the other tanks?

Mr. FOTHERGILL said he did not think so. The principal object of these experiments was to show the value of radiated heat from the fuel on the grate, and the impact of the flame or hot gases. He was of the opinion if the first tank was taken away the efficiency of the second would increase, but he thought it would fall very far short of 100.

Mr. HALL-BROWN said it seemed he had not made himself at all clear in the first remarks he made. What he meant was this:—The formula given in this paper was merely meant to take into account the losses during adiabatic expansion; and as this was the minor loss, the greater loss being the initial condensation, he maintained this formula had very little bearing upon the economy of steam engines.

Mr. WESTGARTH begged leave to supplement his remarks. The author of the paper, he said, concluded that the best engine was the quadruple engine with four-cranks. He quite agreed with him and with Mr. Fothergill as to the necessity of advance in pressures. What he

contended for, however, was not to give up the three-cranks. They could have the quadruple engine and three-cranks by placing the fourth cylinder on top of one of the others, or by other arrangements.

Mr. J. M. ALLAN said there was a question he would like to raise. In this paper the author spoke of the limiting of the piston speed. Supposing it to be suitable for a ship to have engines running at more than 100 revolutions, he assumed that because the piston was 71 inches diameter 100 revolutions would be about the maximum it would be possible to run, owing to the inertia of the reciprocating parts. There were many instances of cylinders of nearly 100 inches running at above 100 revolutions. So, then, it was perfectly plain that engines could be safely worked at those number of revolutions, and with a much greater piston speed. In calculating the pressures required for the acceleration, it was usual to assume that the whole mass of piston, rod, and connecting rod is centred about the crank, and the result found by the formula taken. Before the piston reached the end of the stroke either top or bottom it must come to rest. So they had only to overcome the dead-weight, and not any energy due to velocity. There was a pressure of 14 lbs. per square inch given to accelerate this piston; but that was if it was running at maximum velocity, at the velocity of the crank about. Instead of that he said the piston when commencing was *nil*, and had gradually to be accelerated, and this 14 lbs. seemed too much. If they prepared a diagram of the velocities, and compared it with the crank, they could get out the acceleration; and if in this case they were to divide the circumference of the crank's circle into 10 degree divisions the pressure required to accelerate would be obtained from the distance travelled by the piston while the crank was travelling through 10 degrees, a small amount, which instead of being 14 lbs. would probably be only one-half of it. So to speak of limiting the speed of piston from a calculation like that was, he thought, misleading.

Lieut.-Col. ENGLISH said he could not follow at all the author's argument that there would be no economy by jackets. The writer of the paper took two cases—of a jacketed and unjacketed cylinder—and supposed in the first that 200 thermal units per stroke had been put into the cylinder, and 100 thermal units into the jacket, and to obtain the same conditions in the other case 300 thermal units were put into the cylinder direct. From this the author concluded that the result was the same in both cases. He (Lieut.-Col. English) could not see how there was any illustration at all of the effect of the jacket if one stroke of the engine only was considered; but if the 100 thermal units put into the jacket were

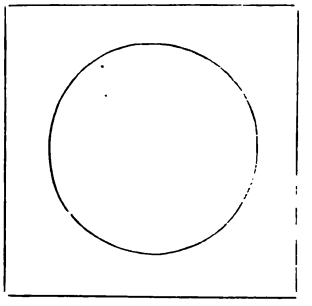
sufficient, as assumed, to prevent condensation, it must be by bringing the interior surface of the walls to a temperature equal to or exceeding that of the incoming steam, when they would remain dry throughout the stroke; and this effect might last for an indefinite number of strokes without requiring a fresh supply of heat to the jacket. As a matter of experiment, there was no doubt but that careful trials of the jacket had a very different result from that assumed by the author. One of the last trials of the Committee on Steam Jackets of the Institution of Mechanical Engineers was carried out on a compound engine under his (Lieut.-Col. English's) control at Woolwich. It showed in two experiments where the horse-power was the same, with a pressure of about 50 lbs., that the effect of jacketing was an economy of over 20 per cent. in this particular engine.

The PRESIDENT—Can you tell us the speed of the piston?

Lieut.-Col. ENGLISH—It was 4 feet stroke and about 60 revolutions per minute. In discussing the effect of surface exposed to initial condensation in simple and compound engines respectively, the author said that the surface was raised in a simple engine to twice the temperature that it had in a compound engine, and that this would serve to show why an economy should result from divided temperature range. So far as he knew, there had been no experiments at all to prove that the surface of the cylinder was raised or lowered to the full amount of the range of temperature of the steam. Experiments, so far as they went, showed the range of temperature of the inner surface of the metal was considerably less than the range of temperature of the steam. Then the author regarded the economy of engines with increased piston speed as very evident. It seemed to him (Lieut.-Col. English) that the author was mixing up increased piston speed and increased number of revolutions. No doubt a large number of revolutions per minute had a very marked effect in reducing condensation; but here, again, there was no experimental evidence to show that the actual piston speed, that is, the number of feet travelled through per minute, had any effect at all on condensation. It seemed a pity that in a paper like this so little reference was made to the results of actual experiment. He (Lieut.-Col. English) could not see how the diagram (Fig. 1, Plate 1) represented the conditions in a steam cylinder. If a known weight of steam were introduced into a hot cylinder, and then partially condensed until the pressure fell to a definite amount during expansion, the diagram would represent the heat distribution; but in a steam cylinder an unknown weight is introduced,

part of which condenses, whilst the pressure is maintained at a uniform amount by a further supply from the boiler; and none of these circumstances are taken account of in the diagram.

The PRESIDENT observed that Mr. Westgarth, who, he was sorry, had left the meeting, read a letter from a gentleman in Hull with reference to the trouble they had had with a boiler like the one alluded to in the paper. In two instances exactly the same trouble had come under his observation, and he tried to realise what was the reason of it, and it always seemed to him this was the reason. Here they had a plate rigidly held at the circumference. Now, if they were to take a piece of drawing paper stretched on a board, and draw a circle on that paper, take a sponge and wet it, they would find it all puckered. If they took their knife and cut it out, and



wet it, they would find it keep perfectly flat. He did not know whether he was right or not, but a plate so held, with a strong heat puckered, and so caused that to which Mr. Spear, of Hull, referred.

The discussion at this stage was adjourned, to be resumed at the next meeting in Newcastle.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890–91.

PROCEEDINGS.

THIRD GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON MONDAY EVENING, DECEMBER 15TH, 1890.

F. C. MARSHALL, ESQ., PAST-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Sunderland, on November 21st, which were approved by the members present, and signed by the Past-President.

The ballot for new members having been taken, the Past-President appointed Messrs. Jas. Patterson and W. Kilvington to examine the voting papers, and the following gentlemen were declared elected:—

MEMBERS.

Evans, Lewis, Surveyor to Lloyd's Register, 3, St. Nicholas' Buildings, Newcastle-on-Tyne.

Hepburn, Alfred, Forge Manager, Northumberland Forge, Wallsend-on-Tyne.

Hodge, Rowland F. W., Manager, Shipbuilding Yard, Messrs. C. S. Swan & Hunter, Wallsend-on-Tyne.

MacColl, Hector, Engineer, Managing Director, Messrs. MacIlvaine & MacColl, Belfast.

Macfarlane, Andrew, Superintendent Engineer to Messrs. Pinkney & Sons, Steam Shipping Company, Sunderland, 26, Thornhill Terrace, Sunderland.

Parsons, Harry F., Engine Draughtsman, Messrs. Wallsend Slipway Company, 3, Eversley Place, Heaton, Newcastle-on-Tyne.

Potts, Matthew, Ship Draughtsman, Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn Shipbuilding Yard, 86, Glen Terrace, Hebburn-on-Tyne.

Simpson, Edward, Ship Draughtsman, Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn Ship Yard, 2, Neptune Road, Wallsend-on-Tyne.

Thompson, John, Engine Surveyor to Board of Trade, Sunderland, 8, The Brae, Sunderland.

ASSOCIATES.

Bacon, William Charles, Shipowner, Chadwick House, West Hartlepool.

Barraclough, Thomas, Shipowner, Messrs. West Hartlepool Steam Navigation Co., West Hartlepool.

Blacklin, Richard James, Messrs. The Hudson Shipping Company, West Hartlepool, Dinsdale House, Brougham Terrace, West Hartlepool.

GRADUATES.

Freeman, Alfred J., Draughtsman, Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's Works, 2, Regent Terrace, Newcastle-on-Tyne.

King, John, Ship Draughtsman, Messrs. R. Stephenson & Co., Hebburn-on-Tyne, 24, Gloucester Road, Newcastle-on-Tyne.

McKenna, Francis, Assistant Engineer to Mr. E. F. Wailes, 46, Hodgson Street, Willington Quay-on-Tyne.

Oxton, Walter, Draughtsman, Messrs. Wigham Richardson & Co., Neptune Works, Walker-on-Tyne.

BUSINESS MATTERS.

Mr. MARSHALL (Past-President), having explained his presence in the chair as being occasioned by the absence of the President in Italy, said there were one or two subjects to which he desired to allude. The desirability of their having, as most institutions of this character had, an annual dinner, or an annual social gathering of some sort, had been discussed by the Council. Circulars were sent out to ascertain the feeling of the members on this subject, and 135 replies were received. He need not say that this was a very small number out of the 750 members, but of the 135, 46 voted for the annual dinner and 87 for a conversazione or some other social gathering, the remainder making no reply at all. It was therefore thought by the members of the Council that with such a division of opinion, coupled with the general indifference evinced by members generally, it was scarcely desirable, for this year at least, to entertain the project of an annual dinner. The question of having a telephone into their offices in St. Nicholas' Buildings, was also discussed at the Council, and it was decided that they should adopt the Post Office system of telephone for the office. It would therefore be within the province and privilege of members to speak to the Secretary whenever they had any grievance or wanted any information from him.

The SECRETARY (Mr. Duckitt), supplementary to the remarks anent a social meeting, stated that he believed there was to be another conversazione of associated societies next spring, but instead of being held in the Durham College of Science, it would be held in the Natural History Museum, where they would have more room and avoid the crush of the last conversazione.

The PAST-PRESIDENT stated that the next meeting would be held on the 10th January at Hartlepool, and the Council had decided that the paper read there would be discussed and closed. There was a suggestion that the discussion on Mr. Hök's paper, to be read that night, should be continued at Hartlepool, it being on a shipping subject, and therefore likely to be interesting to the Hartlepool members. This suggestion—received that evening only—would be discussed by the Council, and if possible adopted. With reference to the representative sub-committee at Lloyd's, mentioned in the agenda, one of the members elected by the Glasgow Institution, and another by the Institution of Naval Architects, London, were still undetermined.

The discussion on Mr. W. R. Cummins's paper on "Increased Boiler Pressure and Increased Piston Speed for Marine Engines" was resumed.

Mr. W. Hök read a paper on "The Unsinkability of Cargo-carrying Vessels."

Mr. M. Sandison read a paper on "Main Steam Pipes."

ADJOURNED DISCUSSION ON MR. W. R. CUMMINS'S PAPER ON "INCREASED BOILER PRESSURE AND INCREASED PISTON SPEED FOR MARINE ENGINES."

The SECRETARY read the following:—

COMMUNICATION FROM MR. H. B. BUCKLAND.

NEWCASTLE-ON-TYNE, *Nov. 20th*, 1890.

DEAR MR. DUCKITT,—I have read Mr. Cummins's valuable paper on the "Increased Piston Speed and Boiler Pressure of Marine Engines," and quite agree with him that we can safely increase the piston speed very considerably and also the boiler pressure. I have not had time to go over all his calculations, but assume them correct, except as regards the boiler. I will pass on to his question: What type of engine will best suit these new conditions? I disagree with him that the choice lies between the three-crank three-cylinder engine and the four-crank four-cylinder engine, for in the first of the two you do not get sufficient range of expansion, and in the second, with the four cylinders, you get the proper expansions, but it necessitates a much greater space occupied by the engines, so that I consider the three-crank four-cylinder engine, with one cylinder tandem, would be more advisable and give better results, taking up the same or less space than the present triple; but better still, a combined vertical and horizontal engine, with four cylinders and two cranks, a design which I believe has lately been patented. This arrangement, as I think you will see, retains the proper expansions, in the four cylinders, necessary for the increased pressure, takes up less room than the old compound engine, and the two connecting rods being on one crank, at right angles, or any other intermediate position, prevents any dead centres. And now I pass on to the boilers. Mr. Cummins says "for the same heating surface." I take this to mean the calculated heating surface, or, as it is better known, paper heating surface. Now, I think it has been many times demonstrated that about the first $1\frac{1}{2}$ or 2 feet of the tube surface, from the combustion chamber end, is equal to all the rest of the tube surface put together in point of efficiency, so that in triple engines of a given power, having boilers say 14 feet diameter and 160 lbs. working pressure, the shell plates are $1\frac{9}{32}$ inches thick, and to get the efficient heating surface for the same powered engine, with 250 lbs. working pressure, with Mr.

Cummins's boiler, I am confident he would have to put them in the same size, if not larger, and thus you would have shell plates of about $1\frac{13}{16}$ inches thick exposed to the fire. We are driven into a corner as far as the present type of cylindrical boiler is concerned, so must seek another form altogether.

We must get the strongest form of a body known, that is a *sphere*. I have lately designed and patented a boiler of the spherical form, and am now having one built at Messrs. Eltringham's works, where I will shortly test its capabilities. (See Plate V.) The bottom part of the shell is made with a semi-spherical plate inverted, and from one to four combustion chambers can be attached to it. The furnace stands below the boiler proper, and is a separate body from the boiler, being jointed to it by suitable knees, bolted, and it forms a feed heater. The flames and gases are broken into two currents, and heated air (natural or forced) is admitted between the two currents in the combustion chambers. When deteriorated, the furnace can be removed and renewed without cutting out a rivet.

With this design, compared with that of the present type of cylindrical marine boiler of the same power, I obtain more heating surface, which I expect will be very much more efficient per square foot, about half the dead-weight, carry less water, have more cleaning room, and take up less space. As there are only about 12 stays against about 125 in the ordinary boiler, the cost of manufacture is much less; and I hope to effect a saving of about 15 per cent. in the coal consumption. The design is passed and approved by Lloyd's, and many members of this Institution to whom I have shown it have expressed their approval of it.

Thanking Mr. Cummins for his valuable paper,

I am, Sir,

Yours faithfully,

H. B. BUCKLAND.

Mr. JAMES PATTERSON said he thought the question of quadruple expansion engines was one not dependent so much upon the engine as the boiler. When they got a boiler which would withstand much higher pressures than at present in use, and with equal safety, then quadruple engines were bound to come to the front. Mr. Fothergill, in discussing this paper, objected to the boiler proposed by Mr. Cummins because the tube heating surface would not be so efficient as the plain box-heating surface of the ordinary type of boiler. He gave them the result of some experiments, from which he deduced that the distribution of the heating surface had a great deal to do with its efficiency. He (Mr. Patterson)

agreed to a certain extent. For instance, he had no doubt that the top half of a tube was more efficient than the lower half, and the surface upon which the flames came directly into contact would be more efficient than where mere radiation took place. But he thought Mr. Fothergill had deduced too much from the experiments he quoted, and had overlooked the fact that the first surface acted upon by the heat would do the greatest duty, and that after that each square foot of surface would do less and less, until practically all the heat that was to be got out of the flame was extracted; so that he thought the small evaporation per square foot of tube surface was principally due to the fact that there was comparatively little heat in the gases when they reached the tubes. In the design presented by Mr. Cummins, the tubes were brought practically nearer the fire, and the tube surface was almost the first reached by the flame, and therefore would be very much more efficient than it was in their ordinary boilers; but he thought this very fact made it an impracticable boiler, because the tube plate was the first surface on which the flame acted. Indeed, the tube plate was the critical part in their present boilers, and the heat that reached it was quite sufficient to make it troublesome. Although much had been extracted from the flame by the furnace and flame box, the heat on the tube plate in Mr. Cummins's boiler would of necessity be much greater, and would without doubt cause the tubes to leak badly. He had not had time to study the design of Mr. Buckland's boiler, but he thought they could not do much better than work on the lines of their present marine boiler, so accessible for cleaning, and which had proved a very good boiler in the past. He thought they might, by degrees, come to a much higher pressure than at present with this type of boiler. As to the type of the quadruple expansion engine to be adopted, some laid stress upon the advantage gained with the three-crank triple over the two-crank compound, on account of the more uniform turning moment on the crank. He had no doubt that was an advantage. The quadruple engine on two cranks should have a more uniform turning moment than the two-crank compound engine, because —with the pressures using at present, at any rate—the cut-off in the quadruple engine was much later, and tended to equalise the turning moment. In a four-crank engine, with the cranks practically at right angles, two and two opposite each other, the weights of the moving parts were balanced and the turning moment still more equal. The three-crank triple could be seen to move more regularly than the compound. He had not seen the two-crank quadruple working, and could not say how it worked, but he could say that the movement of the four-crank

engine was quite as regular as the three-crank triple. He thought Mr. Westgarth showed a design of quadruple with three cranks and two cylinders. This design was essentially bad. To get anything like an equal turning moment in this engine they must have very unequal ranges of temperature, and that was just what it was desirable to avoid. If, on the other hand, they got equal ranges of temperature and ranges of expansion, they got an unequal turning moment. In other words, to obtain equal ranges of temperature in this design it would be necessary to sacrifice the very advantage which it was advanced would be gained—viz., a uniform turning moment. The design is analogous to the triple engine with two cranks and three cylinders; if equal powers were developed on each crank, the ranges of temperature were very unequal, with corresponding loss of economy, which was amply proved by the relative economy of the two-crank and three-crank triples. To get the same economy they should have the range of expansion equal, and consequently a very unequal turning moment. He thought a four-crank quadruple engine would be the engine of the future.

Mr. W. KILVINGTON said he had very few remarks to make on this paper. One thing that struck him as being very important was the determination of the efficiency due to any cause or any altered condition in the working of an engine. With reference to this, perhaps the writer would explain in his reply why he had not adopted the thermodynamic formula instead of the round-about way which he had employed to arrive at the result, and which he might say in passing gives only about half the increase of efficiency at which the author arrives? He would like if the writer would tell them also why 100 lbs. of steam should be expanded only down to 8 lbs., while the 150 lbs. steam is taken down to 6 lbs.? And again, when they came to steam of 250 lbs. the final pressure was taken at 5 lbs. These alterations of the terminal pressure appeared to him to vitiate the calculations so far as they expressed the gain due to increase of pressure, which, he supposed, they were intended to represent, as that was the question under consideration. The author had suggested separate steam and exhaust valves on all the cylinders. Well, there was a great probability that economy in steam would accrue from this, but, at the same time, the increase of cost and complication they would entail, especially in the case of a four-cylinder engine, was a very serious consideration. The paper extended over a very wide range, but the most important of the numerous things referred to was kept for very scant notice at the end, namely, the boiler. He had no doubt that a boiler of the author's design would fail for the reasons which Mr.

Patterson had fully pointed out, and therefore he need not much further enlarge upon it. The boiler would fail by the tubes giving out and leaking at the back end. The flame and hot gases from the fire could not impart any of their heat until they had got to the tube plate, with the result that the transfer of heat would be so rapid that the water could not be kept in contact at the tube plate, and for some distance along the tubes. There was a point at which the temperature at the tube plate was too high for safe working in the marine class of boiler. This point was sometimes reached with boilers of the ordinary type in ordinary working when the grate was long in relation to the furnace; and with forced draught it was very often unfortunately exceeded. If he (Mr. Kilvington) were designing a boiler for 250 lbs. pressure, he should be very careful to convince himself that a boiler of the present type could not be adapted to the purpose before trying such a one as the author proposed. He thought they ought to feel obliged to the author for his very suggestive paper, but he would feel still more grateful if he would in his reply further amplify the points to which he had referred, which, judging from the paper, he will be well able to do.

Mr. R. L. WEIGHTON said that after what had been said that night there was very little left to discuss. The object which the writer had set before himself seemed to him (Mr. Weighton) of the most praiseworthy character, and deserving of all encouragement and commendation. He should like personally to add his support to whatever Mr. Cummins had attempted as something that deserved their appreciation, while they could, nevertheless, point out what they individually considered to be shortcomings. With that preface, he would point out what he individually considered to be some shortcomings. First of all, to commence with the engine, there could be no doubt at all that, theoretically speaking (and it was very easily demonstrated by more methods than one—indeed, by a much more direct method than that adopted by the writer of the paper), there was economy inherent in increased steam pressures; but treating the matter theoretically was begging the question very largely, for they could not have a theoretical engine, that was an impossibility; and the whole trouble arose when they came to design an engine. They all knew they could get a certain gain from increased pressure, but practically the question was, where is the machine that will realise this gain? It seemed to him there was a decided tendency in the present day to assume that it would be just as easy to rise from 150 lbs. to 250 lbs. pressure—to utilise 250 lbs. pressure—as it was to rise from 90 lbs. to 150 lbs. pressure, that

was to say, that the percentage of rise in pressure would give no more trouble. He rather thought there would be more trouble; although, as a set-off and to use a common phrase, "the resources of civilization" were increasing inasmuch as they had got better material and more accurate manufacturing processes to assist progress than was ever previously at their command. They must not forget, however, that higher pressures meant higher temperatures, and the latter tended to disintegrate the internal working surfaces of the engines. Again, there was the ever-increasing difficulty of dealing with the expansions of pipes, etc., which difficulty was largely augmented by increased pressures; and again, high pressures entailed a very large addition to the friction of stuffing boxes, which had to be very tightly packed. The writer went on to deal with piston speeds. Now, it must not be forgotten that the question of the feasibility of higher piston speeds had no relation to the feasibility of higher pressures. It was quite possible to realise whatever economy was inherent in high piston speeds from any engine, whether a triple or quadruple engine, without its being worked with high pressure steam. This question of gain from increased piston speed is mentioned on page 51, where the writer says:—"An increase of revolutions should always tend to economy of steam." He (Mr. Weighton) should say that was so within certain limits, and whether it was so or not in the case of any given engine depended largely on what the present revolutions of that engine were. If the present revolutions were as high as the steam pipes, ports, and passages could efficiently deal with, then any increase of piston speed, instead of giving increased economy, would give the very reverse. So it should not be forgotten that increased piston speed entails (other things being equal) increase of steam and exhaust speeds through the passages, unless the passages, ports, and valves are made of such a size as to keep down that speed; but if they are thus made of large size a certain loss is entailed, first, in clearance space, and, second, in driving large valves; and whilst they might have a gain as shown by the indicator, there might be a loss in power as transmitted to the propeller. For these reasons he thought the author had, unintentionally no doubt, shown this gain in rather a roseate light, and he did not think it could be actually realised to the extent predicted. On page 54 there was a statement which he wished very cordially to support, because he thought it a very often neglected principle amongst superintending engineers and others purchasing and using marine engines, viz.:—"The writer ventures to suggest that cylinder ratios, etc., should be designed so as to obtain equal initial loads in each cylinder." He (Mr. Weighton) would add to that—"and, if

possible, equal ranges of temperature in the cylinders." It was a very common complaint for one to hear that the powers in the cylinders were unequally distributed, as if this necessarily entailed some grievous loss. As a matter of fact it would generally be found that the best distribution of power was when the powers were unequal in the cylinders. The real point to be aimed at in this case was not necessarily equal powers, but equal loads to conserve the bearings, etc., and equal ranges of temperature to conserve the steam. With regard to the much-maligned boiler, he did not think he could add anything of moment to what had been said. He did intend to say something, but his two predecessors had hit largely upon what he had to say. There was only one point he could add to what had been said, and that was this, that in designing boilers he should be inclined to lay it down as a general principle that the flame should always in the first instance, and while at its hottest, impinge upon plates with no seams in them, and that it should not get at the tube plates first, for that was the point at which the greatest evaporation was liable to take place. This was the reason why circular furnaces stood the fire so well—they had no seams on them where the flame impinged. Doubtless, furnaces sometimes collapsed, but this only, to his mind, served to prove that they were habitually at a very high temperature, a temperature at which no seamed plate would remain tight at its seams. This view was confirmed by a study of the action which took place in model boilers. At St. Peter's works they had a series of model boilers with glass sight holes conveniently placed in the shells, and wherever the flame, which was that of a Bunsen burner, was applied in the furnaces, whether at the front end or at the extreme back end, the evaporation from the tube plates was a very large percentage of the entire evaporation of the boiler, he should say from five-eighths to three-quarters of the whole. The globules of steam rising from the tube plate formed a veritable fountain, and the action was very instructive and very striking as showing the large amount of duty done by the tube plates and by the necks of the tubes in the immediate neighbourhood of the tube plates. Let them consider what would probably happen with this boiler of Mr. Cummins's. The heat was carefully shielded from the boiler shell plates until it got to the tube plate, and, as had been already said, the major part of the heat in the incandescent gas would be absorbed by the tube plate and tube ends, the parts least able to stand it; and while he did not think such a boiler as this would give trouble under gentle combustion, he thought if it was forced even to a very small extent trouble would result. The chief heating surface of this boiler, to begin with, was *tube* surface,

and that was the least efficient surface. Mr. D. K. Clark was a very high authority on this subject, and he gave the results of a series of experiments with boilers that had tubes 66 inches long. The first 6 inches of the tubes evaporated more than the whole of the rest of the 60 inches. No doubt the tube surface in the boiler was the least efficient surface. In the model boilers referred to there was scarcely any evaporation at all, except very near to the tube plates. In the boilers of some war vessels with forced draught there was no doubt that, under certain conditions, the water was prevented from having access to the tube plate by reason of the immense generation and up-rush of steam at the tube plate and back end of furnace. There was, as it were, a layer of steam, which was continually ascending and continually being renewed, interposed between the water and the tube plate. This, of course, would lead to a very high temperature in the tube plate and tube ends, and would be quite sufficient to cause leaky tubes. All this in boilers of normal construction, in which the furnace plates received the first of the flame. How, then, could a boiler like Mr. Cummins's be expected to stand under like conditions ?

Mr. MARSHALL (Past-President) said they had had a very interesting discussion on Mr. Cummins's paper. He was sorry he had not the opportunity or privilege of hearing the paper read, and the discussion which took place at the last meeting ; but he thought it had been so thoroughly thrashed out by the three gentlemen who had spoken that night it did not leave much more to be said. He believed if Mr. Cummins had ever heard of a vessel called the "Royal Dane" he would not have advised a boiler of the type proposed by him. That boiler had very much the same kind of arrangement, except that the furnaces were inside instead of outside the boiler. It had failed from precisely the same reasons as Mr. Patterson and Mr. Weighton had pointed out—because of the intense heat upon the tube plates, and the want of absorbing surface, as Mr. Patterson had pointed out, nearer the flame and the hottest part of the gases after leaving the fuel. With regard to the question of three-crank compound engines and three-crank triples being a question at all open for consideration, they had only to remember the fact that the engines of the transatlantic liners "Etruria," and sister-vessel the "Umbria," were just about to be converted into triple expansion engines. The "Etruria" used 390 tons of fuel per day, similar vessels of the same class, with triple expansion engines, burning something like two-thirds of that amount. There was the remark about forced draught and natural draught and long bars. One of their good admirals called forced draught an invention of the evil one ; he was

not quite sure whether he had not something to do with that evil influence. He was willing to bear all the burden incident to the circumstance. He was quite sure that the present requirements of war vessels could not be complied with without forced draught, and he was further perfectly satisfied merchant vessels would be a great deal better for its adoption. The difficulty that did exist in relation to forced draught, as it had been applied, had arisen almost solely from the circumstance Mr. Weighton or Mr. Kilvington had mentioned—the fire bars had been made much too long. In order to ensure greater efficiency with natural draught long bars projecting into the combustion chamber had been adopted, with the result that with even a very moderate measure of forced draught, tube plates and tube ends had been overheated and caused leakage. He was satisfied that with shorter bars and increased air pressure up to something like 3 to 4 inches, instead of 2 inches, the combustion might be intensified to the extent they had in locomotives. Naturally, it followed that if they got that intensity of combustion on the bars the heat was absorbed on the very best place, namely, in the furnaces over the bars and in the combustion chamber, before reaching the tubes. He quite endorsed all that had been said that night about the intensity of the heat and force of evaporation given off on the tube plates. There was no question that, in the model boilers Mr. Weighton alluded to, the force of evaporation was expended on the tube plate; but he thought he had omitted to say at the same time, that the fountain he spoke of, arose, to a certain extent, from the heat given off by the furnaces below it, as the force of evaporation at that point was very great. The flame box back and sides were also very important features, as shown by those model boilers. A large amount of work was done by the combustion chamber back, top, and sides. If they did away with this, as had been done in many boilers in Her Majesty's service, no doubt they would have trouble in the tubes. Referring to the remark made by Mr. Weighton as to the rapidity of evaporation on the tube plate, it was very well exhibited in two classes of boilers with which they lately had to do, both locomotive boilers—a large number of which had been fitted into vessels for the Italian, as well as H.M. Government—and the only way they could account for the difference in the circumstances of those particular boilers arose from the fact, that the disposition of the tubes in the tube plates was different. In those which gave trouble the tubes were placed so that in the vertical direction they were close together. (See Fig. A, Plate VI.) The disposition of those that gave them no trouble were as Fig. B, Plate VI., the only difference

being in the vertical distance from point to point. They were very much indebted to Mr. Cummins. His had been a most interesting paper, and he thought the discussion that had arisen upon it had elucidated a large amount of information of a very valuable character, and they would accord to Mr. Cummins in his absence their very cordial thanks.

THE UNSINKABILITY OF CARGO-CARRYING VESSELS.

By W. HÖK, M.I.N.A.

[Read before the Institution in Newcastle-on-Tyne, December 15th, 1890.]

The object of the present paper is to lay before the members of this Institution an investigation, made for the purpose of ascertaining if the regulations for the subdivision of ships with transverse bulkheads, embodied in Lloyd's rules for iron and steel ships, adequately fulfil the purpose for which they are evidently intended, viz., to enable ships to keep afloat in case they sustain any reasonable damage to their hulls below the water-line, either through collision or through other causes of a serious nature.

To carry out such an investigation is difficult under any circumstances, due to the extreme complexity of the subject, but it has recently been somewhat simplified, on the one hand by the passing of the Load-Line Act, and on the other by the deduction of a few formulæ, by which the work involved in determining the effect of admitting water in ships' holds, placed in communication with the sea, is greatly reduced.

The fixing of a line above which ships must not be loaded facilitated, to a very great extent, this enquiry, for the reason that draught plays therein a very conspicuous part, as will be readily perceived by a perusal of the mathematical part of the paper ; and the formulæ (for their deduction see Appendix A, page 102) make the task of comparing ships of different types, sizes, proportions, and finenesses comparatively easy.

True, the simplicity of the formulæ is due to some assumptions, but it will be found, so the writer hopes, that these assumptions being, indeed, of no importance, will not materially alter the result that would be obtained were no assumptions made, and that, therefore, these formulæ, based as they are on strictly scientific principles, will not only in this investigation, but in all others relating to the unsinkability of ships be of considerable serviceableness. They have been used here, and by their aid the writer expects to reveal a few rather interesting and not generally

known facts about the subject in hand, viz., the unsinkability of cargo vessels; it is, at least, in these expectations he now commences the investigation proper.

THE FORMULÆ.

Call L = length of the ship.
„ d = moulded draught.
„ A = area of the load water-line.
„ I_o = moment of inertia of the load water-line about a transverse axis through the centre of gravity.
„ a = area of the water surface in the compartment to which water is admitted.
„ v = volume of the compartment to draught d.
„ l = centre of gravity of the water in the compartment from the centre of buoyancy of the ship.
„ h = centre of gravity of the water surface in the compartment from the C.G. of the load water-line.
„ δ = ratio of the water admitted to the total volume of the compartment v.
„ ϵ = ratio of the distance of the C.G. of the water-line from the aft perpendicular to the length of the ship.

Then put $\sigma = \frac{v}{ad}$; $n = \frac{A - \delta a}{\delta a}$; $\gamma = \frac{l}{L}$; $\gamma_1 = \frac{h}{L}$; $\alpha = \frac{12\, I_o}{AL^2}$, and

the additional draught forward $= \frac{\sigma d}{an - 12\,\gamma_1^2}\left[\alpha + 12\,\gamma(1-\epsilon)\right]$ (I.)

do. do. aft $= \frac{\sigma d}{an - 12\,\gamma_1^2}\left[\alpha - 12\,\gamma\,\epsilon\right]$ (II.)

do. at the middle of the ship $= \frac{\sigma d}{an - 12\,\gamma_1^2}\left[\alpha + 12\,\gamma\,(\tfrac{1}{2}-\epsilon)\right]$ (III.)

do. at the C.G. of the W.L. $= \frac{\sigma d}{n}$ . . . . . (IV.)

These are the formulæ the writer proposes for calculations of this sort. It will be found that, for their application, very few data are required besides those generally worked out in drawing offices in connection with other calculations; and on this account that the use of these expressions is not so formidable an affair as may appear at first sight. In addition, it may not be out of place to mention here that these formulæ can be reduced to a simpler and more acceptable form in many cases where less accuracy is needed, as will be seen by perusing Appendix A.

THE CONDITIONS FOR UNSINKABILITY.

It is absolutely imperative to clearly define what is here meant by the unsinkability of ships.

If a ship fulfils certain conditions with regard to draught, when *one* of her principal compartments (such compartment being bounded by water-tight bulkheads) is in communication with the sea, she is called "unsinkable;" if she does not fulfil these same conditions she is termed "sinkable." At the same time, it must be clearly understood that the expression "sinkable" does not in any way imply that the ship will actually founder if one of her compartments is in communication with the sea, but merely that she does not fulfil the conditions laid down for unsinkable ships. There may, perhaps, be some justification for applying this latter term to ships that would not actually sink, when we remember that ships which exceed the draught imposed by the Board of Trade are called overladen, although they may not actually be so.

The writer experienced some difficulty in fixing the draughts, above which no ship should be allowed to sink, in order to be distinguished as unsinkable, but finally settled the matter in the rather unsatisfactory way by allowing them to sink to the most extreme draught they would well nigh float on with some degree of security.

Thus the conditions for unsinkability are that, with one of the principal compartments in communication with the sea:—

1.—The draught forward must not exceed 88 per cent. of the sum of the moulded depth to the bulkhead-deck and the sheer forward.

2.—The draught at the middle of the length must not exceed 98 per cent. of the moulded depth to the bulkhead-deck.

3.—The draught aft must not exceed 92 per cent. of the sum of the moulded depth to the bulkhead-deck and the sheer aft.

By the bulkhead-deck the writer means that deck where the bulkheads stop. It is in one and two-deck vessels the main-deck, in three-deck vessels the upper-deck, in spar-deck vessels the spar-deck, and in awning-deck vessels the main-deck. In steamers having raised quarter-decks connected to bridge houses, that deck is the bulkhead-deck aft, but the main or upper-deck forward.

The remaining depths or freeboards fore and aft, viz., 12 and 8 per cent. of the total depth, may perhaps seem unnecessarily large, but it must be remembered that, with these apparently large freeboards fore and aft, only about 2 to 3 per cent. of the depth remains above the water at quarter and three-quarter length of the vessel.

In one single instance the writer thinks he can reduce the stringency

of the rules for unsinkability without being charged with favouritism, that is in steamers with raised quarter-decks connected to bridge houses, for which the draught at the middle of the length is raised to the moulded depth when the *after* compartments are in communication with the sea. This can be done on account of the great protection afforded by a continuous raised quarter-deck and a solid bridge erection.

ASSUMPTIONS WITH REGARD TO THE VESSELS.

Sheer.—In all cases the mean sheer is that adopted by Lloyd's in calculating the freeboard tables. The sheer forward is $\frac{1}{3}$, and the sheer aft is $\frac{2}{3}$ of the mean sheer, and consequently the sheer aft is half the sheer forward.

Subdivision with transverse bulkheads.—All vessels are subdivided according to Lloyd's requirements, both with regard to the number of bulkheads and to the height to which they are carried.

The writer must ask those who are not conversant with Lloyd's requirements for subdivision to refer to the rules, as space and time do not permit him to repeat them here.

Spacing of water-tight bulkheads.—The writer has assumed that steamers under 330 feet in length are fitted with single-ended, and above that length with double-ended boilers. The total length of the engine and boiler compartment, and its position fore and aft, were rather difficult to settle on, as the engine power and the position of the compartment vary to a considerable degree in cargo steamers of equal length ; but finally the following simple formulæ were adopted for expressing the length of the engine and boiler compartment:—

$$\text{For vessels under 330 feet } \frac{L}{10} + 15 \text{ feet,}$$

$$\text{,, over 330 feet } \frac{L}{10} + 25 \text{ feet,}$$

if L is the length of the vessel, and its centre was placed 1 per cent. of the length of the vessel abaft the middle. The collision and after-peak bulkheads were placed at equal distances from the stem and stern respectively, that distance being 8 per cent. of the length of the vessel for steamers 150 feet, 7·1 per cent. for steamers 240 feet, 6·5 per cent. for steamers 330 feet, and 6 per cent. for steamers 400 feet in length.

The position of these four bulkheads being fixed, there still remained to be settled the position of the intermediate bulkheads in the fore and after holds ; and it was decided to make the main hold, in steamers over 280 feet in length, 5 per cent. of the length of the vessel longer than the fore hold, and the two after-holds, in steamers over 330 feet, of equal length.

The adopted lengths of the various compartments will be easily understood by a reference to the following table:—

LENGTHS OF THE COMPARTMENTS IN PERCENTAGE OF THE TOTAL LENGTH OF THE VESSEL.

Length of the Vessel.	Fore-peak.	Comprt. 1.	Comprt. 2.	Engine and Boiler Comprt.	Comprt. 3.	Comprt. 4.	After-peak.	Total.	
		Comprts. 1 and 2.			Comprts. 3 and 4.				
150	8·00	33·00		20·00	31·00		8·00	100·00	
240	7·10	35·78		16·24	33·78		7·10	100·00	
330	6·50	16·11	21·11	14·56	35·22		6·50	100·00	Single-ended boilers.
	6·50	15·36	20·36	17·58	16·85	16·85	6·50	100·00	Double-ended boilers.
400	6·00	15·94	20·94	16·24	17·44	17·44	6·00	100·00	

Trim.—The trim of the vessel, just before one of her compartments is placed in communication with the sea, has a great effect on the unsinkability. If the vessel trims by the stern the fore compartments are placed at an advantage, and the after compartments at a corresponding disadvantage, and *vice versâ*. Therefore the writer thought fairest to assume the trim of all the vessels at the time of the accident to be on level keel, although he well knows that, in many cases, they would actually trim by the head, and, in many other cases, by the stern.

Fineness and Proportions.—In order to make the investigation tolerably complete in some respects, the writer proposes to enquire into the effects, on the unsinkability, of varying the fineness and proportions of the vessels compared. He has for that purpose not only fixed two finenesses, ·700 and ·790, and two proportions 12 and 15 depths in length, depth being counted to the bulkhead-deck, but also chosen the range of these variations sufficiently extensive to therein include the majority of existing cargo-carrying vessels.

Draught.—The draught at which the vessels are tested with regard to unsinkability is in all cases Lloyd's summer load draught. Originally the writer intended to investigate *one* fineness only, and chose his tonnage coefficient so as to make sure that the vessels would not be considered overladen. Afterwards, when he decided upon investigating the influence of fineness on the unsinkability, his first intention was to work out the true draughts for the fuller vessels also; but finding that the necessary correction was exceedingly small within the range of

fineness he proposed to investigate, he did not carry out that intention, but used the same draughts for the full as for the fine vessel, although this is, of course, not strictly right. Therefore the finer vessel is loaded a trifle under her disc (about 2 inches for the largest size), and the fuller just the same amount over her disc. As this difference is exceedingly small, the writer ventures to assert that none of his conclusions with regard to the influence of fineness on the unsinkability are in the smallest degree affected by the slight discrepancy in the draught, to which the vessels are loaded.

Loading.—The vessels are all supposed to be coal-laden. That cargo is chosen for many reasons, among which the writer may mention the most important. It is an extremely common cargo; it will in the majority of cases completely fill the holds to the bulkhead-deck when the vessel is at her load draught; it does not easily change its nature by contact with sea water; and the amount of water it would admit, in case of damage to the vessel, can be so easily calculated with tolerable accuracy, or so cheaply ascertained by a simple experiment. However, in cases where that cargo does not fill the holds, it is assumed to do so, principally because such an assumption greatly simplifies matters, and also because that condition of loading puts the vessel to a test of less severity than if possibly empty spaces in the compartments under the bulkhead-deck were taken into account.

AMOUNT OF WATER ADMITTED.

(A) Into the holds.—The writer has estimated the amount of water a coal cargo would admit, and found that in a given space filled with broken coal, 60 per cent. is occupied by solid coal and 40 per cent. by air, which latter space would, of course, be filled with water in case it was admitted. No doubt, the amount of empty space varies to some extent with the quality of the coal and with the stowage, so that, therefore, the 40 per cent. must not be considered an invariable ratio; however, the writer believes that, if it be borne in mind that there are spaces between frames, beams, and under the ceiling which admit nearly 100 per cent., the supposition here made that coal-laden vessels admit 40 per cent. of water, in case of their compartments being in communication with the sea, is no exaggeration.

(B) Into the engine and boiler compartments.—Assuming the side bunkers full with coal, and allowing for the displacement of engines and boilers and other machinery, it is probable that the engine and boiler

compartment admits not less than 70 per cent. of water, on which figure the unsinkability of steamers having that compartment damaged is based.

The writer must, at this stage, express his regret that so many assumptions have to be made in order to confine the investigation within workable limits. It is evident that there are thousands of vessels, nay, perhaps every vessel, that are in some respects different to those here selected, but it is also equally plain that there is no need for examining every existing vessel in order to prove in a general way the sufficiency or insufficiency of her subdivision. At first sight it may appear necessary also to enquire into the unsinkability of vessels with a different spacing of bulkheads, but it will be found further on that although in a few instances a different spacing would effect a slight improvement in the vessels, it would certainly, in the majority of cases, aggravate their condition.

TYPES OF VESSELS COMPARED.

The writer has selected seven different types for examination, viz., one, two, and three-deck vessels without erections; these vessels with erections, consisting of poop, bridge, and forecastle, covering ·5 of the length of the vessel; vessels with poop or raised quarter-deck connected to bridge houses, and forecastle, covering ·7 and ·9 of the length of the vessel respectively, the former vessel representing a steamer with a short, and the latter a steamer with a long bridge; the spar-deck vessel; the awning-deck vessel, and the sailing vessel.

Vessels with shorter erections than ·5 of the length are excluded from this enquiry, because their unsinkable properties are easily interpolated when the unsinkability of the first two types is known.

LENGTHS OF VESSELS.

The writer will consider vessels from 170 to 400 feet in length for all types, with the exception of the spar-deck type, the lower limit of length for which he is compelled to fix to 280 feet, due to the incompleteness of the freeboard tables.

It is, therefore, plain at this juncture that the writer intends to investigate the unsinkability of vessels of seven different types, of two finenesses, of two proportions, and of lengths varying from 170 to 400 feet, all loaded with cargo admitting 40 per cent. of water. But he is obliged to limit the number of varieties that may grow out of combining these elements of difference, and therefore proposes to only prepare

three sets of diagrams, each consisting of six plates. The first set will show, for varying lengths, the unsinkability of vessels of 12 depths in length, and of ·700 in fineness. The second set will combine vessels of 12 depths, with a coefficient of fineness of ·790; this set, therefore, compared with the first set, showing the influence of fineness, whereas the third set will, by combining 15 depths in length with a fineness of ·700, show the influence of proportions on the unsinkability.

Of these sets of diagrams, only the first set (Plates VII. to XII.) is printed in connection with the paper. The other two sets, being similar in nature to the first set, would only encumber the Transactions to no purpose, and are therefore omitted; but what the writer has learnt from them will be found further on in the body of the paper, and in the two tabulated statements (Tables II. and III., pages 101 and 102) that are appended.

INTERPRETATION OF THE DIAGRAMS (PLATES VII. TO XII.).

Each of the six diagrams of the first set represents one distinct type of vessel. No diagram for the seventh type, or the sailing vessel, was made, as the unsinkability of that type can be easily ascertained without such assistance. (Appendix B, page 107).

The abscissæ represent lengths of vessels, and the ordinates the draughts to which the vessels would sink if one of their principal compartments was admitting water. There is one draught curve (in black) for each principal compartment, being three for steamers under 280 feet, four for steamers between 280 and 330 feet, and five for steamers above 330 feet. Across these lines just mentioned, three other lines (in red) of a different nature are drawn, representing the maximum draughts forward, middle, and aft respectively, to which the vessels are allowed to sink in order to fulfil the conditions for unsinkability laid down at the beginning of the paper.

It is, then, plain that the relative position of these two sets of lines determine the unsinkability.

The diagrams have to be so interpreted that wherever the draught lines appertaining to the vessels are below those representing the maximum draughts, the vessels are unsinkable; where, on the other hand, the former are above the latter, the vessels are sinkable, and consequently that the intersection of these lines fixes the points on the length scale, where the change from unsinkability to sinkability takes place, or in other words the minimum length for unsinkable vessels.

INFLUENCE OF TYPE.

Diagram 1, Plate VII.—One, two, or three-deck vessels without erections.—The relative position of the curves shows that all steamers of this type under 205 feet in length are sinkable, whatever compartment may be damaged; that from 205 to 280 feet the only unsinkable compartment is the engine and boiler room; that from 280 to 330 feet these steamers would sink if the after-hold was struck, and that above the latter length they are unsinkable.

Diagram 2, Plate VIII.—Vessels with poop, bridge, and forecastle.—The behaviour of this type is much similar to that previously treated, the only difference being that here no vessel under 255 feet is unsinkable, no matter what compartment may be struck.

Diagrams 3 and 4, Plates IX. and X.—Vessels with forecastles having poops or raised quarter-decks connected to bridge houses, the erections covering seven-tenths or nine-tenths of the length of the vessel.—It will be noticed that on these two diagrams three additional curves are drawn. These three curves only refer to the raised quarter-deck type, and have nothing whatever to do with vessels having long poops. The black dotted curve represents the draught at the middle of the length in case the after-hold is damaged, and the two others (red dotted) the maximum permissible draught aft and middle in case of damage to that same compartment. (In calculating the first of the latter curves the raised quarter-deck was in all cases assumed 4 feet in height.)

Perhaps here is the very place for mentioning that the only draught that need be calculated in this enquiry is for that end of the vessel where the damage is situate except in the case just mentioned, or otherwise very small raised quarter-deck steamers would appear unsinkable if damaged abaft the engine room.

A singular exception with regard to the rules for *water-tight* bulkheads exists in raised quarter-deck steamers built on the web-frame principle. If the depth to the top of the raised quarter-deck at the centre line of the vessel is between 24 and 28 feet, and the after-hold fitted with web-frames, carried up to the raised quarter-deck, a water-tight bulkhead is prescribed to be fitted aft, about half-way between the engine room and the after-peak bulkheads. In that exceptional case alone, raised quarter-deck steamers are the only steamers under 330 feet in length that are unsinkable aft; and it will therefore be understood that in the examination of the unsinkability of the after compartment in raised quarter-deck steamers under 330 feet in length, the above steamers are exempted.

Long poop steamers.—Discussing now Diagrams 3 and 4, and con-

sidering, in the first instance, steamers with long poop (the erections covering ·7 length) (Diagram 3) it will be found that no such steamer under 285 feet in length is provided with one single compartment small enough to prevent foundering in case of collision; that at 285 feet the engine and boiler compartment becomes unsinkable, at 295 feet the fore-hold, at 325 feet the main hold, and that first at 340 feet every compartment gains the distinction of unsinkability.

If the erections cover ·9 length (Diagram 4) the matters grow worse. Here no steamer under 310 feet in length is provided with one single unsinkable compartment, the engine and boiler room is secure at 310 feet, and remains so, except for a short length from 330 to 340 feet, this anomaly being due to the increased length of boiler room for steamers above 330 feet, the fore-hold becomes unsinkable at 330 feet, the main hold at 355 feet, No. 3 hold at 360 feet, and finally the aftermost hold at 375 feet, at which length all steamers of this type are unsinkable.

Raised quarter-deck steamers.—On the other hand raised quarter-deck steamers over 330 feet in length are a great deal superior aft, as their compartments so situated are all unsinkable. There is, however, no superiority in case of damage to the engine and boiler room or the fore compartments, and therefore raised quarter-deck steamers with erections covering ·7 length are first completely unsinkable at 330 feet, and with erections of ·9 length at 355 feet.

Diagram 5, Plate XI.—Awning-deck steamers.—Now analysing Diagram 5, or that representing the awning-deck steamer, the revelations here made are far from cheering. The fact is that no awning-deck steamer under 350 feet in length is provided with one single unsinkable compartment. The fore-hold becomes unsinkable at that length, the engine and boiler room at 365 feet, compartments 2 and 3 at 385 feet, and at last the aftermost compartment at 400 feet. Thus no awning-deck steamer under 400 feet in length, constructed according to Lloyd's rules with regard to subdivision, is unsinkable if loaded with a cargo admitting 40 per cent. of water.

Diagram 6, Plate XII.—Spar-deck steamers.—There is now only one type of steamer left for examination, and were it not for that type, and that type alone, the prospects of finding anything satisfactory in the subdivision of steamers would be very small indeed. The spar-deck steamer, unlike its predecessors, presents a different spectacle from the point of view of unsinkability, and if that most unfortunate omission of the bulkhead forward, in steamers under 280 feet, and aft, in those under 330 feet, was not even here to be found the subdivision of these steamers

would be sufficient to secure them a fair amount of freeboard, be it forward, middle, or aft, in case of their compartments being placed in communication with the sea.

Sailing vessels.—Nothing encouraging can be said about this type. It is easy to show by a short and simple calculation (Appendix B, page 107) that if sailing vessels are struck abaft the collision bulkhead they have a chance of escaping foundering, and the reason is simply this, that they, by the rules, require no subdivision at all.

After completed inspection of the seven different types of vessels, the first thought that must forcibly strike every one is the exceedingly great influence of "type" on the unsinkable qualities of vessels. From the spar-deck steamer which would be, but for an unfortunate omission, practically unsinkable, matters gradually grow worse and worse until the awning-deck steamer is reached, which type is first entirely unsinkable at 400 feet in length, and the sailing vessel which is in all cases sinkable and completely deprived of any means of preventing a disaster.

The following list will give some idea of the relative merits of the different types with regard to unsinkability :—

(1) Spar-deck vessels.
(2) One, two, and three-deck vessels, without erections.
(3) One, two, and three-deck vessels, with erections, consisting of poop, bridge, and forecastle.
(4) Raised quarter-deck steamers, with short bridge.
(5) Steamers with poop connected to short bridge houses.
(6) Raised quarter-deck steamers with long bridge.
(7) Steamers with poop connected to long bridge, and forecastle.
(8) Awning-deck steamers.
(9) Sailing vessels.

Now, having completed the examination of the influence of type on the unsinkability, the influence of fineness and proportions remain to be investigated.

INFLUENCE OF FINENESS.

As stated in another place, the writer has, while maintaining the same proportions of depth to length, and similar spacing of bulkheads, varied the fineness so as to ascertain its influence on the unsinkability. It appears, then, that although the influence of fineness, at least within the small range here examined, and which range, nevertheless, embraces the majority of cargo-carrying vessels, must be subordinate to that of "type," yet its main features are not altogether without interest and importance.

As the vessel increases in fulness, the danger of having the end compartments struck becomes more and more apparent. This very inferiority of full vessels is, however, of this advantage, that it improves the unsinkability of their central portion.

Now, as increased fulness aggravates the condition of the end compartments, and improves that of the centre compartment, it follows that the influence of a change in the fineness on the intermediate compartments (2 and 3) is small, and that there is a position somewhere between the ends and the centre where a variation in the fineness of the vessel has no influence on the unsinkability at all. But all that is of more immediate importance to remember is the fact that the end compartments in full vessels must be made shorter than in fine ones. This is plainly seen by a comparison of the influence of fineness on holds 1 and 2. In the fine vessel, damage to No. 2 hold is of far greater consequence than damage to No. 1 hold, whereas, in the full vessel, although No. 1 hold is 5 per cent. of the length of the vessel shorter than No. 2 hold, its effect on the unsinkability is far greater.

INFLUENCE OF PROPORTIONS.

In order to ascertain the influence of varying the proportions, the writer has, while retaining the same coefficient of fineness, ·700, made similar calculations for vessels of 15 depths in length to those already executed.

So as to clearly understand a comparison of the results obtained, the best procedure—the writer believes—is to introduce here, before proceeding further, some preliminary explanation as to the effect of changes in the proportions on the various elements influencing the unsinkability.

With a fixed length of vessel, a decrease of depth, so as to arrive at vessels of 15 depths in length, produces two simultaneous changes in the relation between draught and depth, or in the draught ratio. One is purely due to the diminished depth, and tends to increase the draught ratio, the other is due to the vessel becoming of greater length in relation to depth, and tends to lessen that same ratio. This penalty put on great length in relation to depth is considerable in spar-deck and one, two, or three-deck steamers without erections, and with erections consisting of poop, bridge, and forecastle, whereas it is only one-half the latter amount in steamers with a raised quarter-deck or a long poop, and smaller still in steamers with an awning-deck. Thus, the baneful influence of increased draught ratio due to decrease of depth is counterbalanced by this penalty for excessive length, but to a different degree in the various types,

this penalty being most effective in spar and flush-deck steamers, but nearly ineffective in raised quarter-deck, long poop and awning-deck steamers.

However, this advantage due to the penalty put on excessive length is of insufficient amount to compensate for the increased draught ratio due to decreased depth ; and were it not so, that the decrease of depth also caused the maximum draught ratio (fore and aft, but not centre) to which vessels may sink to be termed unsinkable, to increase (this being due to the sheer being only dependent of length), thus in one sense raising the limits for unsinkability, the writer is afraid that vessels of 15 depths in length would turn out inferior to those of 12 depths. Now, fortunately, it is not generally so, and it will, in all probability, not be difficult after a moment's reflection to comprehend (1) that the unsinkability of the engine and boiler room is always adversely affected by this change in the proportions ; and with respect to the other compartments (2) that their condition has improved in one, two, and three-deck steamers without erections, and with erections consisting of poop, bridge, and forecastle, and in spar-deck steamers ; (3) that the condition of the after compartments of the raised quarter-deck steamer has improved ; (4) that the long poop steamer and the fore compartments of the raised quarter-deck steamer with a short bridge are only slightly affected ; (5) that the condition of the long poop and the fore compartments of the raised quarter-deck steamer with a long bridge is generally worse ; and finally, (6) that awning-deck steamers of 15 depths are, all round, much inferior with regard to unsinkability.

The writer has also prepared three tables (Tables I., II., and III., pages 101 and 102) showing the minimum lengths of vessels at which the various compartments become unsinkable for the purpose of not only forming a check on the statements put forth in the part of the paper dealing with influence of fineness and proportions, but also with a view to presenting these very statements in a more attractive and intelligible form. The figures given are lifted direct from the curves, and are obtained by reading off the length of vessel at which the maximum draught lines intersect the lines representing the draughts in the damaged condition.

TRANSVERSE STABILITY.

It is needless to say that possible changes in the transverse stability by the admission of water, should also be inquired into ; but as an exhaustive treatment of that subject does not form part of the writer's intentions with the present paper, it will be dismissed with a few general remarks.

The change in the transverse stability by the admission of water in vessels at their load draught generally amounts to a slight increase in the metacentric height and considerable decrease in the value of the angle of vanishing stability. On account of this increase in the metacentric height the subject loses its immediate importance, as vessels provided with ample metacentric height in their loaded condition suffer no loss to their initial stability by the admission of water. On the other hand, the importance of providing against the increased danger caused by the loss of range of stability must be recognised in the determination of the limits of draught at which vessels should be considered unsinkable.

The present investigation is now finished. Some questions, however, remain to be considered in connection with the subject, such as the influence of sheer, the influence of varying the percentage of water admitted, and a few minor points, and also the all-important problem, "How is a vessel to be subdivided so as to be unsinkable?" and "What is the smallest number of compartments required for that purpose?" It is evident that it would be futile to attempt a solution of the latter problems before the following questions are settled :—

1.—Are the formulæ used in the present investigation accurate enough for solving these problems?

2.—What should be the minimum freeboard, forward, middle, and aft, to ensure unsinkability?

3.—What percentage of water should be supposed to be admitted in vessels, built for general trading purposes, in case of damage?

4.—Is it sufficient, in attempting to provide adequate subdivision, to assume that only one of the principal compartments is in communication with the sea?

It would also be of general advantage if the members of this Institution, besides giving a decisive answer to the above questions, would also record their experience with regard to the amount of water admitted by such cargoes as grain, cotton, wool, tea, coal, etc.

The writer is sure that it would be a simple matter for many members to make some trifling experiments to the effect of ascertaining the quantities of water admitted by the most common cargoes, and he is also certain that such information, if collected and printed in the Transactions, would be of the utmost value, as it would, among other things, greatly facilitate and advance the solution of the all-important problem : "Which is the proper subdivision for cargo-carrying vessels?"

TABLE I.

SHOWING THE MINIMUM LENGTHS AT WHICH VESSELS OF 12 DEPTHS IN LENGTH, WITH A COEFFICIENT OF FINENESS OF ·700 AND ADMITTING 40 PER CENT. OF WATER, ARE UNSINKABLE.

COMPARTMENT.	One, Two, and Three Deck.	With Erections, ·5 Length.	Raised Quarter Deck and Erections, ·7 Length.	Long Poop and Erections, ·7 Length.	Raised Quarter Deck and Erections, ·9 Length.	Long Poop and Erections, ·9 Length.	Awning Deck.	Spar Deck.	Sailing Vessel.
Compartment 1 ...	under 280	under 280	295	295	330	330	350	under 280	Sinkable for all lengths.
Do. 2 ...	under 280	under 280	325	325	355	355	385	under 280	
Do. 1 & 2 ..	280	280	...	...	...	...	...	280	
Engine and Boiler Room	205	255	285	285	310 & 340	310 & 340	365	under 280	
Compartment 3 ...	under 330	under 330	330	330	330	360	385	under 330	
Do. 4 ...	under 330	under 330	330	340	330	375	400	under 330	
Do. 3 & 4	330	330	...	...	...	...	...	330	
Do. 3 & 4 (Draught at the middle of length)	...	...	300	...	330	...	...	...	

TABLE II.

SHOWING THE MINIMUM LENGTHS AT WHICH VESSELS OF 12 DEPTHS IN LENGTH, WITH A COEFFICIENT OF FINENESS OF ·790 AND ADMITTING 40 PER CENT. OF WATER, ARE UNSINKABLE.

COMPARTMENT.	One, Two, and Three Deck.	With Erections, ·5 Length.	Raised Quarter Deck, Erections, ·7 Length.	Long Poop, Erections, ·7 Length.	Raised Quarter Deck, Erections, ·9 Length.	Long Poop, Erections, ·9 Length.	Awning Deck.	Spar Deck.	Sailing Vessel.
Compartment 1 ...	under 280	310	330	330	365	365	395	under 280	Sinkable for all lengths.
Do. 2 ...	under 280	under 280	310	310	345	345	375	under 280	
Do. 1 & 2	280	280	...	...	...	...	...	280	
Engine and Boiler Room	200	250	280	280	305 & 335	305 & 335	360	under 280	
Compartment 3 ...	under 330	under 330	330	330	330	360	390	under 330	
Do. 4 ...	under 330	350	330	380	330	over 400	over 400	under 330	
Do. 3 & 4	330	330	...	...	...	...	...	330	
Do. 3 & 4 (Draught at the middle of length)	...	...	315	...	330	...	...	...	

TABLE III.

SHOWING THE MINIMUM LENGTHS AT WHICH VESSELS OF 15 DEPTHS IN LENGTH, WITH A COEFFICIENT OF FINENESS OF ·700 AND ADMITTING 40 PER CENT. OF WATER, ARE UNSINKABLE.

COMPARTMENT.	One, Two, and Three Deck.	With Erections, ·5 Length.	Raised Quarter Deck, Erections, ·7 Length.	Long Poop, Erections, ·7 Length.	Raised Quarter Deck, Erections, ·9 Length.	Long Poop, Erections, ·9 Length.	Awning Deck.	Spar Deck.	Sailing Vessel.
Compartment 1 ...	under 280	under 280	under 280	under 280	330	330	355	under 280	Sinkable for all lengths.
Do. 2 ...	under 280	under 280	295	295	365	365	over 400	under 280	
Do. 1 & 2	280	280	280	280	...	...	...	280	
Engine and Boiler Room	205	260	315	315	380	380	over 400	under 280	
Compartment 3 ...	under 330	under 330	330	350	330	390	over 400	under 330	
Do. 4 ...	under 330	under 330	330	365	330	over 400	over 400	under 330	
Do. 3 & 4	330	330	...	...	...	...	...	330	
Do. 3 & 4 (Draught at the middle of length)	...	...	330	...	330	...	...	...	

APPENDIX A.

DEDUCTION OF THE FORMULÆ.

Call L = length of the ship.

„ d = moulded draught.

„ A = area of the water-line at draught d.

„ a = area of the water surface in the compartment to which water is admitted at draught d.

„ I_o = moment of inertia of A about a transverse axis through the centre of gravity.

„ v = volume of the compartment to draught d.

„ δ = ratio of the space in the compartment occupied by water to the total volume v.

„ l = centre of gravity of the water in the compartment from the centre of buoyancy of the ship.

„ h = centre of gravity of the water surface in the compartment from the centre of gravity of the water-line A.

„ also d_1 = mean draught of the ship after admitting water.

„ „ v_1 = volume of the compartment to draught d_1.

Then assuming the water-line at draught d_1 to be equal to A—

$$d_1 = d + \frac{\delta v_1}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

also $v_1 = v + a(d_1 - d)$; or as $d_1 - d = \frac{\delta v}{A}$. . (from (1))

$$v_1 = \frac{v}{1 - \frac{\delta a}{A}}.$$

This latter expression involves the assumption that a will not materially alter for a slightly increased mean draught.

Now call $$\frac{A}{\delta a} = m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1\frac{1}{2})$$

and v_1 is $$= \frac{m}{m-1} \times v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Consequently from (1) and (2)—

$$d_1 = d + \frac{v}{a(m-1)};$$

or calling $$m - 1 = n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2\frac{1}{2})$$

$$d_1 = d + \frac{v}{an};$$

and the additional draught $= \Delta = \frac{v}{an}$ . . . . . (3)

TRAVEL OF THE CENTRE OF BUOYANCY.

Call the travel of the centre of buoyancy $= l_1$, and

$$l_1 = \frac{\delta v_1}{W} \times l$$

if W is the total volume of the ship at draught d; or—

$$l_1 = \frac{1}{n} \times \frac{\left(\frac{v}{a}\right)}{\left(\frac{W}{A}\right)} \times l \quad . \quad . \quad \text{(from } 1\frac{1}{2} \text{ and } 2\frac{1}{2})$$

Call $$\frac{v}{ad} = \sigma \text{ and } \frac{W}{Ad} = \pi;$$

and $$l_1 = \frac{1}{n} \times \frac{\sigma}{\pi} \times l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This is, consequently, the travel of C.B.

TRIM.

The trim is the travel of C.B. $\times \frac{\text{length of ship}}{\text{longitudinal metacentre above C.G.}}$;

but put for simplicity—

$$\text{Trim} = \text{travel of C.B.} \times \frac{\text{length of ship}}{\text{long. metacentre above C.B.}} = \frac{l_1 \times L \times W}{I}.$$

Calling h_2 = C.G. of the damaged water-line from the aft perpendicular—

$$\text{Trim forward} \ldots \quad = (L - h_2) \times \frac{l_1 W}{I} \quad (5)$$

$$\text{,, aft} \quad = -h_2 \times \frac{l_1 W}{I} \quad (6)$$

$$\text{,, at the middle of the length} = \left(\frac{L}{2} - h_2\right) \times \frac{l_1 W}{I} \quad (7)$$

$$\text{,, at C.G. of the water-line} = 0 \quad (8)$$

CENTRE OF GRAVITY AND MOMENT OF INERTIA OF THE DAMAGED WATER-LINE.

h = centre of gravity of a from C.G. of A.

h_1 = ,, ,, A $- a$,, ,, A = the travel of C.G.

$h + h_1$ = C.G. of a from C.G. of A $- a$.

Then if δa is the lost surface—

$$A\, h_1 = \delta\, a\,(h + h_1);$$

or

$$h_1 = \frac{\delta\, a}{A - \delta\, a} \times h = \frac{1}{\frac{A}{\delta a} - 1} \times h$$

$$= \frac{1}{m - 1} \times h = \frac{h}{n} \quad (9)$$

Call I_o = moment of inertia of the undamaged water-line,

and $I = I_o + Ah_1^2 - \left[i + \delta\, a\,(h + h_1)^2\right]$

if i = moment of inertia of $\delta\, a$ about its own centre of gravity.

If, now, i is put = 0, and $\delta\, a = \frac{A}{n+1}$ and $h_1 = \frac{h}{n}$

$$I = I_o + A\frac{h^2}{n^2} - \frac{A}{n+1}\left(h + \frac{h}{n}\right)^2$$

$$= I_o + Ah^2\left[\frac{1}{n^2} - \frac{\left(1 + \frac{1}{n}\right)^2}{n+1}\right]$$

$$= I_o - \frac{Ah^2}{n} \quad (10)$$

= moment of inertia of the damaged water-line about its own centre of gravity.

Put also $I_o = \frac{a}{12} A L^3$ and $h = \gamma_1 L$, and, finally,

$$I = \frac{A L^3}{12 n} \left[a n - 12 \gamma_1^2 \right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Now, calling $l = \gamma L$, the following expression is obtained by an easy reduction:—

$$\frac{l_1 W}{I} = \frac{12 \sigma \gamma d}{L (a n - 12 \gamma_1^2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

What is now required is to find the value of h_2, and the problem is solved.

$$\text{Put } e = \frac{\text{C.G. of undamaged water-line from aft perp.}}{\text{Length of ship.}}.$$

Then $h_2 = L - h_1$. As $h_1 = \frac{h}{n} = \frac{\gamma_1 L}{n}$, $h_2 = e L - \frac{\gamma_1 L}{n}$, and therefore

$$L - h_2 = L \left[(1 - e) + \frac{\gamma_1}{n} \right]$$

$$- h_2 = - L \left[e - \frac{\gamma_1}{n} \right]$$

$$\frac{L}{2} - h_2 = L \left[(\tfrac{1}{2} - e) + \frac{\gamma_1}{n} \right].$$

Thus, the trim forward $= \left[(1-e) + \frac{\gamma_1}{n} \right] \times \frac{12 \sigma \gamma d}{a n - 12 \gamma_1^2}$ and the additional draught forward—

$$= \frac{\sigma d}{n} + \frac{\sigma d}{a n - 12 \gamma_1^2} \times 12 \gamma \left[(1 - e) + \frac{\gamma_1}{n} \right]$$

$$= \frac{\sigma d}{a n - 12 \gamma_1^2} \left[a + 12 \gamma (1 - e) - \frac{12 \gamma_1}{n} (\gamma_1 - \gamma) \right].$$

Putting $\frac{12 \gamma_1}{n} (\gamma_1 - \gamma) = 0$,

the additional draught forward—

$$= \frac{\sigma d}{a n - 12 \gamma_1^2} \left[a + 12 \gamma (1 - e) \right] \quad . \quad . \quad . \quad . \quad . \quad (\text{I.})$$

The additional draughts aft, at the middle of the ship and at the C.G. of the damaged water-line are easily found, being—

$$\text{Additional draught aft} = \frac{\sigma d}{a n - 12 \gamma_1^2} \left[a - 12 \gamma e \right]. \quad . \quad . \quad (\text{II.})$$

$$\text{Do. middle of length} = \frac{\sigma d}{a n - 12 \gamma_1^2} \left[a + 12 \gamma (\tfrac{1}{2} - e) \right] \quad (\text{III.})$$

$$\text{Do. at C.G. of W.L.} = \frac{\sigma d}{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{IV.})$$

These are the expressions to be used in calculations of this kind.

SIMPLIFIED FORMULÆ.

In many instances the centre of gravity of the load water-line is practically at the middle of the length of the ship. Then ϵ may be put $= \frac{1}{2}$, and

the additional draught forward $= \frac{\sigma d}{\alpha n - 12\gamma_1^2}\left[\alpha + 6\gamma\right]$. (I.) bis.

Do. do. aft $= \frac{\sigma d}{\alpha n - 12\gamma_1^2}\left[\alpha - 6\gamma\right]$ . . (II.) bis.

Do. do. ½-way $= \frac{\sigma d}{\alpha n - 12\gamma_1^2} \times \alpha$ . . . . . (III.) bis.

Do. at C.G. of W.L. $= \frac{\sigma d}{n}$ . . . . . (IV.) bis.

when $\delta = \frac{v}{abd}$ = water-line coefficient of fineness of the compartment ;

$$n = \frac{A - \delta a}{\delta a} = \frac{A}{\delta a} - 1 ;$$

$\gamma = \frac{l}{L}$ = ratio of the C.G. of the water admitted from the C.B. of the ship to the total length of the ship ;

$\gamma_1 = \frac{h}{L}$ = ratio of the C.G. of the water surface in the compartment from the C.G. of the water-line to the total length of the ship ;

$\alpha = \frac{12\, I_0}{A\, L^2}$ = Coefficient of moment of inertia of the W.L.

NOTE.—The values of γ and γ_1 are negative when the after compartments are damaged.

It may, perhaps, be interesting to show what form these expressions take in the simple case of a rectangular box.

It is evident that here

$\sigma = 1$; $\alpha = 1$; $\gamma = \gamma_1$; and

Additional draught forward $= \frac{d}{n - 12\gamma^2}\left(1 + 6\gamma\right)$;

Do. do. aft $= \frac{d}{n - 12\gamma^2}\left(1 - 6\gamma\right)$;

Do. do. ½-way $= \frac{d}{n - 12\gamma^2}$;

Do. do. C.G. of W.L. $= \frac{d}{n}$;

where γ = ratio of the centre of the compartment from the centre of the box to the total length.

$n = \frac{1}{\delta\beta} - 1$ if δ = percentage of water admitted.

and β L = length of the compartment.

APPENDIX B.

It is easy to prove that sailing vessels, laden with coal, or cargoes admitting 40 per cent. of water, are not unsinkable.

Say coefficient of fineness ·700;

Coefficient of fineness of the load water-line ·848;

Additional draught at the C.G. of the water-line is $= \frac{\sigma}{n} \times d$,

$$\text{and draught} = d\left(1 + \frac{\sigma}{n}\right)$$

$$\sigma = \frac{v}{ad} = \frac{W}{Ad} = \frac{\text{Block coeff.}}{\text{Water-line coeff.}} = \frac{\cdot 700}{\cdot 848} = \cdot 826$$

$$n = \frac{A}{\delta a} - 1 = \frac{1}{\delta} - 1 \text{ as } A = a$$

$\delta = \cdot 4$; $n = 1 \cdot 5$, and draught $= d\left(1 + \frac{\cdot 826}{1 \cdot 5}\right) = 1 \cdot 551 \times d$.

This draught, in the damaged condition, must not be greater than ·98 depth, in order to comply with the conditions for unsinkability, and therefore the load draught must not exceed $\frac{\cdot 98}{1 \cdot 551}$ depth $= \cdot 632$ depth; but as the load draught of all sailing vessels exceeds that draught, it follows that they are all sinkable.

DISCUSSION.

The PAST-PRESIDENT said they had a very important paper before them, and the question in his mind at that time was whether they should commence the discussion that night or defer it until the Hartlepool meeting? Mr. Sandison's paper had to be read that night, as there were models that could not very well be carried about. They might perhaps just open the discussion and adjourn it to the next meeting.

Mr. H. MACOLL thought the discussion should be opened that night so far as practicable, and as their next meeting would be at Hartlepool, which was a district embracing a very large amount of shipbuilding, it would be well to devote a definite time, however limited, to the discussion of Mr. Hök's paper by the local members. This paper, it might be said, was the first of two papers, and the writer was very desirous of obtaining the views of the members on the points raised, and the answers which might be given to the questions put would materially influence the treatment of the subject of bulkheads in

the second paper. And, of course, the sooner these replies were given the sooner Mr. Duckitt would receive the paper for the consideration of the Reading Committee and circulation amongst the members. Therefore, he would suggest a limited portion of the time at the Hartlepool meeting should be given to the discussion of Mr. Hök's paper, and the discussion could be then adjourned, and concluded at the next meeting in Newcastle.

This proposal was accepted.

Mr. J. JOHNSON thought they were greatly indebted to Mr. Hök for bringing an old subject—the subdivision of ships into water-tight compartments—before the Institution in a new and rather novel form. Of course it was well-known, without such elaborate calculations as these, that ordinary cargo-carrying vessels, provided with the usual number of water-tight bulkheads as demanded by Lloyd's rules, stood a very poor chance of preserving sufficient reserve buoyancy in case of one of the largest compartments being in free communication with the sea, and, no doubt, the authorities at Lloyd's were as well aware of the fact as anybody else. The writer of the paper had only allowed for one compartment being filled with water at the time, and he was sure this was not enough. In order to make ships as nearly "unsinkable"—as the writer termed it—as possible, they must divide them somewhat after the style of the most modern Atlantic liners, and thus enable them to float with two or even three compartments in communication with the sea. However, from a commercial point of view, he thought it would hardly be fair to make the subdivision of ships subject to further legislation than what was embodied in Lloyd's rules; but it would, no doubt, be reasonable to expect that some consideration was taken on this point when assigning freeboards. At the first perusal of the paper fault might be found with the amount of assumptions which formed, as it were, the basis upon which the results were obtained, and also that the ships had not been taken at their exact freeboards; but as steamers were constantly changing draught and trim when at sea, an approximate load line was quite near enough for practical purposes. He would suggest to their studious young members and Graduates to make themselves well conversant with the Appendix, as he considered it a very good example of what could be done by way of mathematical reasoning when approximate formulæ were considered sufficient for some particular purpose. Very few text books in naval architecture gave such approximate formulæ as could be of every-day use in the drawing office. As a rule each designer had to find his

own short cuts by experience. He would like to ask Mr. Hök a question regarding some points in the Appendix. In obtaining formula (10) the moment of inertia of the lost portion of the water-line was put = 0. Especially in smaller ships where there were only two holds, the water-line surface of these holds formed a very large portion of the total water-line surface, and therefore he should like to know how much error was involved in assuming $i = 0$?

Mr. De Rusett said he had only just seen the paper, and really had not had time to study it for remarks; but from experience in this kind of calculation, it was not clear to him that the author was correct in assuming that the class of vessels under consideration could be filled with coal without being over their assigned draught, consequently shutting out water which would otherwise fill empty spaces, and hence still further endanger the safety of the vessel by reducing the very small margin of freeboard left for the relatively safe vessels. He should like to study the valuable paper more fully before making any further remarks.

Mr. H. Macoll said the questions raised by Mr. Hök were very important. The first consideration in a sea-going vessel was that the structure should float, and next, the power of keeping afloat should be as great as practicable. Although we were not in the habit of considering an ordinary cargo vessel as a life-saving appliance, there could be little doubt if institutions such as our own went in solidly for safety, especially in the way of increasing the number of water-tight divisions in all vessels, they would be very heartily supported by the classifying and underwriting corporations. Whether the shipowner, who had, in the first instance, to pay for those additions, or the stevedore, who had to get the vessel's cargo discharged as quickly and cheaply as possible, would look on this matter with the same feelings was very problematical. And it would require very great caution to be observed in this matter. He by no means objected to making ships as safe as practicable, but it was quite possible to so subdivide ordinary mercantile vessels, keeping only the maximum safety point in view, that their usefulness would be very materially interfered with. As all ships were, more or less, of a compromise, generally more, it was not the simplest matter possible to arrange for the greatest practicable subdivision, and also retain facilities for working the vessels and their cargoes economically. The conditions of, say an Atlantic passenger liner and a small coasting collier of 1,500 tons dead-weight and 110 nominal horse-power, were essentially different; the former carried a large number of people at all times, and speed, safety,

and comfort, not to say luxuriance, were expected and looked for, and competing lines vied with each other in supplying these requirements; whilst in the case of the latter, the primary consideration in the cargo vessel seemed to be the conveyance of the greatest possible amount of goods at the lowest possible rate, and speed was by no means a primary consideration; and bulkheads in those steamers were looked upon by the stevedores as more of a hindrance to the work of loading and discharging than anything else. In fact, the ideal collier for a stevedore was a vessel with as much of the deck made portable in the shape of hatches as possible, small hatches and bulkheads being looked upon as unmitigated nuisances. So much for the general question of bulkheads. With regard to Mr. Hök's paper it contained much valuable information, and the process of predicting the results of filling the various compartments was distinctly a great step in advance of anything he had seen on the subject, and he regretted being called on to speak without having been able to give the paper the attention and study it so well deserved. One was rather staggered with the results of the calculations so far as the awning-deck steamers were concerned, and looking into two steamers he was surprised to find the assumptions made in Mr. Hök's paper were fully borne out; and he did not see any reason to doubt that the assumptions made in the paper were in any appreciable manner at variance with the facts, taking vessels of ordinary types into consideration. One thing, by the way, occurred to him in reference to the freeboard tables. It was rather curious to note that 4 feet seemed to be the *ne plus ultra* of height for a break or raised quarter-deck. If your vessel was 8 feet hold, and did not possess a quarter-deck 4 feet high, a penalty in the shape of increased freeboard was made, and if the vessel was 32 feet hold, the same magic of 4 feet in height was all that was asked for. No doubt, erections or superstructures were, when properly proportioned and constructed, of great service; but taking the case of a small vessel, with a long raised break extending over the machinery placed amidships, in the case of injury to the engine rooms, these would be little benefit to the ship either in buoyancy or stability; and a lower break, with greater freeboard, would make a safer vessel. Again, in the case of a large vessel with a longitudinal bulkhead, it would be easy to show how in a cargo vessel, when fully laden, and receiving injury on one side, admitting water, the effect would be to give the vessel such a heavy list as to be unmanageable. The large passenger steamer, in virtue of greater freeboard and greater reserve buoyancy, under the same circumstances, might be brought through, after sustaining a serious injury, without

much difficulty. He wished to record his appreciation of Mr. Hök's labours as given in his paper, which was a formidable task to fulfil single-handed, and although the exigencies of attending to load-lines, life-saving gear, etc., had prevented the speaker from giving Mr. Hök the answers to his questions as put in the paper, he hoped that during the continued discussion the desired expressions of opinion would be forthcoming from the members of the Institution.

The discussion was then adjourned.

MAIN STEAM PIPES.

By MAGNUS SANDISON.

[Read before the Institution in Newcastle-on-Tyne, December 15th, 1890.]

Few problems connected with recent practice in marine engineering deserve more attention at present than that of main steam pipes.

Increased pressures and temperatures having necessitated, both as regards construction and management, a revised version of the marine engine, questions such as the following forcibly present themselves in this connection:—

Is the material now generally employed in the construction of main steam pipes all that can be desired?

Are the principles which ought to regulate the connecting up of a series of boilers to the engines on board ship sufficiently recognised by standard authorities on the subject?

Dealing with the first of these queries the writer begs to submit the following contribution to the Transactions of the Institution, in the belief that many members may be interested in examining the steam pipe which has been sawn up and is now laid on the table for inspection.

They will thus have an opportunity, which he believes has seldom been afforded, of satisfying themselves as to the nature of the action which may be expected to take place in *wrought iron* main steam pipes under the conditions ordinarily prevailing at sea.

Of course, wrought iron pipes, and cast iron, have been from the infancy of mechanical engineering extensively used on land for the conveyance of steam, and while the mere transference from a stationary to a marine engine involves no radical change of condition, their use under these circumstances has been very limited and information as to their durability or suitability non-existent, or at the best extremely scanty. Fears have been expressed by some that rapid corrosion or pitting would take place, and that flakes of oxidised material would be carried over into the cylinders to the detriment of the internal working parts. These fears would appear to be groundless.

Recent experience having demonstrated the uncertainty attending the use of solid drawn copper as a material for steam pipes, it occurred to the

writer, while discussing the substitution of steel for solid drawn copper, that Mr. Alexander Taylor, in the early days of triple engines and high pressures, had adopted wrought iron in some cases for steam pipes. An interview with that gentleman resulted in an agreement to the effect that were a new pipe fitted in one of these vessels the old one could be removed for experimental purposes.

This pipe the writer has the honour, with the permission of his firm, to lay before the Institution.

It was fitted by Messrs. Douglas & Grant, Dunnikier Foundry, Kirkcaldy, in February, 1882, on board the S.S. "Claremont," owned by Messrs. Fisher, Renwick, & Co., of Newcastle, and has therefore been running under the conditions ordinarily prevailing in the mercantile marine for the past eight and a half years.

The tube itself is lap-welded and made by Messrs. A. & J. Stewart, of Glasgow. The flanges are screwed on and brazed.

The pipe is 5 inches external diameter and the estimated speed of steam through it is 3,520 feet per minute. This is low, the pipe being large as compared with ordinary practice.

The invoiced thickness of the pipe was ·375 of an inch. It is now, after eight and a half years' continuous service, ·32 to ·375 of an inch thick, being practically the same as when new.

The interior surface of the tube exhibits no signs of pitting or corrosion. It is covered by a thin crust of black oxide, the maximum thickness of which does not exceed $\frac{1}{32}$nd of an inch. Where the deposit is thickest it is curiously striated by the action of the steam. This effect is very well shown by Plate XIII., which is reproduced from a photograph of the actual pipe. On the scale being removed the original "bloom" on the surface of the metal is exposed.

Externally, the pipe, which was not lagged or protected in any manner, has suffered slightly from corrosion.

It is interesting to note that the scale on the interior surface was strongly magnetic. This was seen when the samples were ruptured in the testing machine.

Tensile tests of the material give the following results:—

Sample.	Dimensions.			Ultimate Stress in Tons per Square Inch.	Extension in 4 Inches.
	Breadth.	Thickness.	Area.		
	Inch.	Inch.	Sq. Inch.		Per Cent.
No. 1.—With Grain ...	·93	·375	·348	19·5	23·0
„ 2.—Across „ ...	·735	·32	·235	17·9	5·0

Using the results given by sample No. 2, the pipe is still enormously strong, having a factor of safety of no less than—

$$\frac{17{\cdot}9 \times 2240 \times {\cdot}64}{150 \times 4{\cdot}25} = 40.$$

Arguing from the present condition of the "Claremont's" steam pipe it would appear that wrought iron steam pipes, irrespective of diameter, are, to say the least of it, as durable and reliable as copper, no matter how manufactured, and the writer would take the present opportunity of thanking Messrs. Fisher, Renwick, & Co. and Mr. Taylor for their courtesy in this matter.

The foregoing remarks may, *per se*, appear of insufficient value to merit the attention of members, but the writer would point out that this question of steam pipes has not yet been discussed in any shape or form by the Institution. That steam pipes, from one cause or another, do give out, though happily such cases are comparatively rare, and that the consequences are generally disastrous, is a sufficient warrant for a discussion on the causes of and the means for preventing or minimising these mishaps.

Most engineers are aware that for the last three or four years there has been a feeling approaching uneasiness, if not of actual "scare," throughout the engineering profession in this connection. This feeling has been induced, not without reason, by a series of accidents, unfortunately attended in some instances by serious loss of life.

The following list briefly recapitulates the cases to which through the daily prints most public attention has been directed:—

Date.		Killed.	Injured.
Sept., 1887	Royal Mail S.P. Co.'s S.S. "Elbe" ...	11	...
March, 1888	North German Lloyd S.S. "Lahn" ...	3	...
July, 1889	London Electric Supply Corporation, Ld.	1	10
April, 1890	French Ironclad "Requin"	3	...
Aug., 1890	Russian „ "Sinope"	7	11

Many of you will doubtless have noticed in this morning's papers (by way of coincidence) that another very serious case has to be added to the preceding list. With your permission I shall read an extract from the *Telegraph* of to-day's date:—"By the explosion of a steam-pipe on board the British India steamer 'Jumna,' in the Albert Docks, on Saturday, several of the firemen were seriously injured and had to be taken to the Seamen's Hospital. Three of them have since died, and two others are

in a dangerous condition." This vessel was launched on the Clyde in 1886, and was fitted with quadruple expansion engines to work at 160 lbs. pressure.

As bearing further upon this point, the writer has also thought it well to reproduce *in extenso* a circular recently issued by Lloyd's relating to the same subject :—

Circular No. 737.

LLOYD'S REGISTER OF BRITISH AND FOREIGN SHIPPING,
2, WHITE LION COURT, CORNHILL, E.C.,
30*th December*, 1889.

COPPER STEAM PIPES.

GENTLEMEN,—I am directed by the Committee of this Society to bring under your notice the particulars of the bursting of a copper steam pipe which have recently been reported to them by the Society's Chief Engineer Surveyor.

The pipe in question formed one of the branch bends of the main steam pipes of a new Atlantic steamer; its internal diameter was 8 inches, its thickness ·272 of an inch, or No. 2 W.G., and it was made by one of the most eminent firms of coppersmiths in the kingdom, with a brazed joint in the usual manner.

Before being placed in the ship this pipe was tested by hydraulic pressure to 320 lbs. per square inch, or twice the working pressure, on three different occasions, with satisfactory results. Nevertheless when bolted in its place, and while being subjected to a hydraulic test, for the purpose of proving that all the joints were tight, it gave way at a pressure of 310 lbs. per square inch, and tore for a length of 20 inches, near to the brazing, the material at the point of fracture presenting the appearance of having been partially cracked during the operation of brazing.

From tensile tests cut from the pipe in the vicinity of the fracture, and also away from the injured part, it was ascertained that the material had a tenacity of 33,000 lbs., showing that the copper was of good quality, and taking the dimensions of the pipe into consideration it should have been capable of resisting a pressure of about 2,200 lbs. per square inch before giving way; the fact of its failing at a pressure of 310 lbs. per square inch is of so alarming a character that the Committee think it right to suggest that it is deserving of your serious consideration.

In consequence of accidents having occurred with brazed pipes, some Engineers have adopted solid drawn pipes, others have hooped them, while others have lapped them with wire, but these are quite exceptional cases, and the Committee do not think it desirable at present to go further in this matter than to place the facts that have come under their notice in connection with such cases before those who are interested in the subject.

You will remember that the Committee drew your attention some little time since to the circumstance of a calamitous accident that happened on the S.S. "Elbe," of an exactly similar nature to this one.

I am, Gentlemen,
Your obedient Servant,
B. WAYMOUTH,
Secretary.

Taking the first three cases in the preceding list, we find Mr. Parker, in his paper read before the Institution of Naval Architects in 1888, considered the true explanation of the explosions of the steam pipes both of the "Elbe" and "Lahn" to be the accidental cracking of the copper after being slightly overheated during *the brazing operation.*

Mr. Traill, of the Board of Trade, states in his report that the Deptford explosion was caused by the deficiency of strength of the brazed copper bend, *the brazing* of both seams and flanges being defective.

In endeavouring to avoid the vicissitudes of brazing, as exemplified in the preceding cases, attention has been turned to solid drawn pipes. It would seem, however, that implicit confidence is by no means to be placed in them. As in steel so in copper ingots a small blow-hole or impurity in the casting will develop during the process of drawing into a serious flaw. Doubtless, the same observation applies to sheet copper, but in solid drawn tubes, where there is less working up, faults are more likely to be concealed, and their elimination, *i.e.*, the production of absolutely pure copper, will undoubtedly constitute a problem of vital importance to the manufacturer in the future.

It may be remarked at this stage that the power required to bend seamless pipes of large diameter and gauge is in excess of the capacity of most existing coppersmiths' presses, and calls for more efficient arrangements: moreover, where bending is required great care is necessary, as once the required curve is exceeded a pipe cannot readily be bent back again.

Illustrating still further the uncertain character which copper piping, both brazed and solid drawn, has recently acquired, it may be mentioned that in future vessels the Admiralty require *all* steam pipes above 8 inches in diameter, whether brazed or solid drawn, to be wound with copper wire, in order "to make up their strength which would be impaired by the presence of obscure weak places, and generally to prevent rupture should the pipe itself be weak at any point." Further, a set of solid drawn copper tubes, 14½ inches in diameter, which recently passed through the writer's hands, were condemned during the process of working up owing to obscure flaws (such that no factor of safety was competent to cover) manifesting themselves when the tubes were heated, and *steel* steam pipes were substituted for them.

The quality of steel which is now obtainable in the shape of welded tubes may be gathered to some extent from the following tests cut from a tube 2½ inches external diameter and ·135 inch thick:—

No.	Description.	Dimensions.			Ultimate Stress.		Ex. in 8 Ins.
		Breadth.	Thickness.	Area.	Total.	Sq. In.	
		Inch.	Inch.	Inch.	Tons.	Tons.	p Cent.
1	Lengthwise, Plain ...	·945	·135	·127	3·29	25·9	20·0
2	„ Welded	1·0	·155	·155	4·35	28·0	20·0
3	Crosswise	·98	·135	·132	3·40	25·7	19·0
4	Piece of tube, 2 in. long, flattened under steam hammer until sides are close together. No sign of fracture.						
5	Piece of tube, 2 in. long, hammered down endwise to 1·18 in. No sign of fracture.						

The writer would conclude with some remarks bearing on steam pipe arrangements aboard ship. Figs. 2 and 3, show two methods of

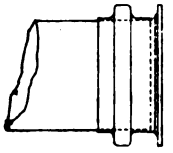


Fig. 2.

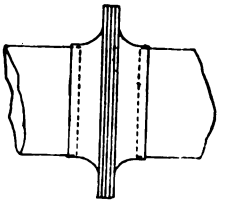


Fig. 3.

providing for the expansion of copper steam pipes now in vogue, both entailing a large amount of objectionable brazing. These, moreover, as well as plain expansion bends, inasmuch as they provide for expansion by stressing the material, are only applicable for short lengths of pipe. For long ranges the socket joint must be introduced.

The following is extracted from the Board of Trade instructions issued in 1887 as to the survey of the hull and machinery of Steamships:—"In all cases in which a socket expansion joint is fitted to a bent steam pipe, the surveyor should require a fixed gland and bolts to be fitted, in order to prevent the end of the pipe being forced out of the socket. This regulation should be complied with in all cases of bent steam pipes fitted with socket expansion joints. It is also desirable that fixed glands and bolts should be fitted to the expansion joints of straight steam pipes, as cases have occurred, particularly with small straight pipes, in which the ends of the pipes have been forced out of the sockets."

Mr. Seaton, in his *Manual of Marine Engineering*, describes the fitting alluded to as follows:—"It has sometimes happened that pipes have

blown out of a Faucit joint owing to there being a bend near it on which the steam pressure acted; in all cases of this kind a collar should be brazed to the pipe, some 12 or 18 inches from the gland, through which bolts pass, connecting it to the flange of the stuffing box on the other pipe that it may not draw out."

Manifestly in the cases referred to by the Board of Trade the expansion joints were unnecessary, and it is now becoming recognised that the remedy sanctioned by the Board for preventing the recurrence of similar mishaps does not meet the case in an effectual or efficient manner, even assuming the stress to be provided for takes the form of a "water hammer" blow at the bend. Not only is additional brazing involved (unless, indeed, this is avoided by forming the check flange on a tail casting to which the pipe is jointed in the usual manner) but *the function of the expansion joint is nullified by the fixed gland* should the arrangement of the pipes be such as to allow the latter to become operative, *i.e.*, should the bending moment due to the action of the steam exceed the moment of resistance of the section.

The outward pressure on the bend should be taken up *at the bend* either by bridle stays or by a suitable abutment similar to what is usually provided in the case of water mains, leaving the straight length of the pipe free to expand into the socket joint.

The writer thinks that in many cases more consideration could profitably be bestowed on the arrangement of the main leads of steam pipes in the way of making them as simple, as direct, and *as little liable to unknown stresses as possible*, whether these stresses be due to steam pressure, expansion, the presence of water, or any combination of these.

He trusts that this paper, which only professes to open up the subject, and which has left many points untouched, may be the prelude to an interesting discussion.

DISCUSSION.

The PAST-PRESIDENT directed attention to the pipes on the table. He said they were extremely interesting. There was not the slightest appearance of scoring or deterioration, and he thought this fact was confirmed by a letter they had from a distinguished engineer which Mr. Duckitt would read:—

COMMUNICATION FROM MR. A. E. SEATON.

13*th December*, 1890.

DEAR SIR,—I am exceedingly obliged to you for the copy of Mr. Sandison's paper that you have been good enough to send me for perusal. I have not, however, had time to read it through very carefully, and as I have to be in London on the 15th inst., it will be impossible for me to be with you and take part in the discussion, as I should very much like to do, interested as I am in the question of steam pipes for machinery.

It may be of interest to your Institution to learn that in 1883 we fitted two steamers for the Great Eastern Railway Company with main steam pipes and feed pipes of cast iron (80 lbs. pressure), and during the past year both these ships have been in our hands for examination, and we found that the pipes were not apparently wasted or otherwise injured, although they have been in constant use for seven years. We have fitted other boats for the same company, which have not been running so long, with cast iron pipes (90 lbs. pressure), and when examined they proved to be in equally good condition.

I have for a considerable time advocated the use of steel and iron for feed pipes and main steam pipes in lieu of copper, and I believe that they may be adopted with great success. I see no reason why there should be greater waste with them than is observable in the steam spaces of marine boilers or in the other parts exposed to steam only when made of either cast iron, wrought iron, or steel.

The high pressure cylinders of the boats mentioned above as fitted with cast iron steam pipes have been seen by us yearly, and there is no sign whatever that they have been affected by such pipes, or that scale from the pipes has been carried to them and injury produced by scoring, etc. Great care was taken by us to provide sufficient and efficient expansion joints to admit of the extension of the pipes and free movement of them from other causes, so that they should not be strained in any way beyond that due to internal pressure.

I shall be very pleased to receive from you when it is published a copy of the discussion on the paper, and at any time to contribute an expression of my views on any points on which your Institution may desire the same.

I should also like to become a member if your rules admit of it.

I am, dear Sir,

Yours faithfully,

A. E. SEATON.

The PAST-PRESIDENT intimated that there was another contribution to this paper from the Broughton Copper Company, Limited. He did not know how this contribution had come; he believed it was at the request of Mr. Sandison.

Mr. SANDISON—The Secretary sent a copy of the paper.

The PAST-PRESIDENT—As these gentlemen were not members of their Institution, it might be looked upon rather as a trade advertisement; but, with their pleasure, he would read it, as it seemed to be a question of "copper *versus* steel."

COMMUNICATION FROM THE BROUGHTON COPPER CO., LIMITED.

DEAR SIR,—We have to thank you for a proof copy of the above paper, and assuming that your object is to give us an opportunity of stating our views on the subject we venture to make the following remarks:—

The writer of the paper appears to recommend welded iron or steel tubes, entertaining the opinion that seamless tubes are liable to defects that welded tubes are not liable to. In this opinion we cannot agree.

Tubes with the joint welded are subject, first, to defects in the flat metal, and, secondly, to defects in the welding process.

Tubes properly made without a longitudinal joint or seam are free from a great liability to defects in all seamed pipes, and it is well known that the modern process used in England, Germany, and France by such houses as Armstrong, Whitworth, Krupp, and others, produces tubes from ingot iron or steel free from blow-holes and other defects.

The whole system of modern artillery is based on the production of perfect cylinders and tubes, and which, owing to experience and suitable appliances, is now reduced to a simple process. Artillerists dare not entertain a suspicion of unsoundness, and all welding in the manufacture of cylinders and tubes is abandoned in consequence.

As to copper tubes, we believe that no firm is able to manipulate so as to ensure absolute soundness the large masses of copper requisite to produce the very largest tubes; but this will soon be overcome; and if no house has hitherto done this, it is entirely owing to the persistence in using large brazed copper tubes because of their low cost, thus giving no encouragement for incurring the large outlay necessary for the erection of suitable plant.

Copper in its treatment for the production of very large tubes which shall be perfectly reliable requires a process very analogous to that used

for ingot iron or steel, and engineers may rely that very soon they will be able to obtain such large copper tubes as free from defects as the best steel tubes.

As to copper tubes produced by electricity, this is as yet uncertain; they cannot so far be produced without defects.

We send you a piece showing a fracture of such a tube, which shows great laminations and irregularity in structure.

If you can favour us with a report of the discussion on Mr. Sandison's paper we shall be glad.

Believe us, dear Sir,

Yours obediently,

THE BROUGHTON COPPER CO., LIMITED.

The PAST-PRESIDENT (referring to the sample sent by the Broughton Copper Co.) said this piece of copper was, he presumed, deposited by the Elmore process, and consisted simply of a series of leaves which might be very easily detached the one from the other. This sheet of copper, about a quarter of an inch thick, was laminated throughout. In regard to Mr. Seaton's letter, he might say that he (the Past-President), thirty years ago, fitted a number of steamers for the London and St. Petersburg Company, with cast iron and wrought iron steam pipes and feed pipes. It was just at the time of the introduction of surface condensation, when it was thought necessary to avoid everything in the nature of copper, in order to keep away the evil influence of pitting in the boilers. The feed pipes were made of wrought iron, and the steam pipes of cast iron, with some parts of wrought iron. There was considerable difficulty with some of those pipes. There was oxidation, exfoliation, and certainly pitting in a good many of the pipes. At that time they were only very imperfectly acquainted with the principles that ought to guide them in the use of surface condensation. The working pressure at that time was 30 or 35 lbs.—35 lbs. being about the most they were using at that time in those special engines. Nine years ago they fitted machinery to a large vessel in the river Tyne, and she had throughout cast iron steam pipes and, he believed, was running to this day with those pipes. They were for the same company to which Mr. Seaton had alluded—the Great Eastern Company, on the Harwich route. Personally, he saw no objection to these pipes. If they would allow him, he would just like to mention another point in connection with this subject of iron tubes. Mr. Sandison had pointed out iron tubes were by no means

so strong crosswise to the grain as longwise. The difference is 1·6 tons. This, to a large extent, is got rid of in steel tubes, but in steel tubes they were always liable to the imperfections arising from welding. An attempt to overcome this had been made, which was now being successfully worked; and he would give them an outline from a letter he had received from a late colleague, Mr. Milton, now of Lloyd's, who had been good enough to send him a very extended account of the process of manufacture he witnessed at the Landore Steel Company's Works. The object of this process was to produce steel tubes absolutely weldless, because absolutely solid to begin with. The process consisted of putting the solid steel bar, heated to a white heat, of the diameter they wished to make the tubes, between two conoidal rollers, as shown in Fig. 1, Plate XIV. These rollers were about 18 inches diameter, and ran from 400 to 500 revolutions per minute. The bar was put in through a tube at the smaller end of the rollers, and owing to the position in which these were placed, their axes being slightly inclined or angular to each other, the effect of drawing this bar in between the two rollers was to make it hollow, and it became an absolute tube by the time it had got through the rollers placed as shown. A plain bar became a tube by means of the excessive strain put upon the external parts of the metal, due to the increased velocity of the larger part of the conoidal rollers, causing them to twist as this part of the bar came through the rollers, revolving at a greatly increased velocity. A bar 2 inches in diameter would have a hole in it of about three-quarters of an inch, a bar of 4 inches a hole of about 1½ inches. In order to make it into a finished tube for the market, this bar was put in between two similar conoidal rollers, and a mandril the exact size of the interior of the tube, placed as shown in Fig. 2, Plate XIV., leaving exactly the thickness between the two surfaces required. The result was the tube formed in these rollers became a tube of the size required, perfectly weldless, homogeneous, and a finished article. It was a very ingenious process and, he understood, was extremely successful, and if they could get tubes of that character of steel he would say the question of copper steam pipes was solved. The fact of their getting a perfectly homogeneous tube without a seam was really all they wanted. These tubes were being made now from 4 inches up to 10½ inches in diameter, and they quite expected to make tubes for furnaces of 3 feet to 4 feet in diameter. That was what they were aiming to produce out of a solid bar in the way he had very imperfectly attempted to describe. There

was one special feature about these tubes, though it applied to any ordinary solid drawn tube, it afforded an excellent opportunity for fitting Pope's joint; a pipe of that kind could be easily expanded to form the flange without damage or risk to the material itself.

The discussion was adjourned.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

FOURTH GENERAL MEETING OF THE SESSION, HELD IN THE ATHENÆUM, CHURCH STREET, WEST HARTLEPOOL, ON SATURDAY EVENING, JANUARY 10TH, 1891.

H. MACOLL, ESQ., VICE-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Newcastle-on-Tyne on December 15th, which were approved by the members present and signed by the Vice-President.

The ballot for new members having been taken, the Vice-President appointed Messrs. J. R. Fothergill and A. Leckie to examine the voting papers, and the following gentlemen were declared elected:—

MEMBERS.

Seaton, Albert Edward, Civil Engineer, Messrs. Earle's Shipbuilding Co., Hull.

Wadagaki, Yasuzo, Engineer Draughtsman, Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's-on-Tyne.

ASSOCIATES.

Allison, J. S., Shipowner, West Hartlepool.

Conner, L. R., Shipowner, Exchange, West Hartlepool.

Steel, George, Shipowner, 77, Church Street, West Hartlepool.

GRADUATES.

Beale, Harry, Apprentice Draughtsman, Messrs. C. S. Swan & Hunter, Wallsend-on-Tyne: Otterburn Villas, Newcastle-on-Tyne.

Davis, Thos. Wilfred, Engineer Draughtsman, Messrs. R. & W. Hawthorn, Leslie, & Co.: 1, Race Street, Newcastle-on-Tyne.

Rowntree, Stanley, Apprentice Ship Draughtsman, Messrs. C. S. Swan & Hunter, Wallsend-on-Tyne: 62, Neptune Road, Wallsend-on-Tyne.

Smithson, Alfred Edward, Engineer Apprentice, Messrs. R. W. Hawthorn, Leslie, & Co., St. Peter's-on-Tyne: 1, Dawson Square, Tynemouth.

MR. LECKIE'S PAPER.

The VICE-PRESIDENT expressed his regret that they had to forego having Mr. Leckie's paper before them that night, it not being completed in time, and as it would be a very valuable and important contribution they wished to have it in as good shape as possible before submitting it to the members. Considering the counter attractions in the Hartlepool district of skating and political meetings it was a pity that their gathering had not been postponed for a week or two, but as all the arrangements were made some time since it could not well be deferred. He hoped, however, they would have a warm and animated meeting.

Mr. J. D. YOUNG read a paper on "Mechanical Aid to the Investigation of Experimental Curves."

The discussion on Mr. W. Hök's paper on "The Unsinkability of Cargo-Carrying Vessels" was resumed.

Mr. W. R. Cummins not being in attendance, his reply to the discussion on his paper on "Increased Boiler Pressure and Increased Piston Speed for Marine Engines" was taken as read.

MECHANICAL AID TO THE INVESTIGATION OF EXPERIMENTAL CURVES.

By J. DENHOLM YOUNG, Wh. Sc.

[Read before the Institution, in West Hartlepool, on January 10th, 1891.]

The acknowledged value of known graphic and mechanical methods of calculation has led the writer to bring before the members of this Institution a mechanical appliance which may be found useful as a labour-saving machine in engineering and other calculations.

The use of curves in recording the results of experimental data has long been apparent to practical men; and the value of a curve as compared with an algebraic symbol, or a table of numerical quantities, is instinctively felt by every investigator, as the curve shows clearly at a glance the tendencies of the forces or factors involved, whilst mere tabular numbers do not in general convey a very clear impression of this kind without careful study. Even such a simple case as the law of gravitation, $S = \frac{1}{2} g T^2$ presents itself much more forcibly to the mind when represented in a graphic form.

Such curves as—

$$xy^{\pm 2} = C,$$

or

$$xy^{\pm 3} = C,$$

are easily produced with the help of a table of squares and cubes, and, as is well-known, instruments have been devised for the direct production of conics and some other curves. But the delineation of, say Rankine's adiabatic curve, $PV^{\frac{10}{9}} = C$, is not so readily performed, and requires the use of logarithmic tables for its evaluation—a work of considerable patience, and, to many persons, of considerable mental effort. It is with a view to expediting such processes as these that the system presently to be explained may be applied.

It is almost unnecessary to state at this point that examples will only be brought forward as illustrations of a method of working, and not with the object of advancing any particular theories, the object of the writer being to show how each investigator may proceed in his own line.

By the means about to be described we may discover at sight, within the limits of the instrument employed—

1.—Any whole or fractional power of a number.

2.—Any whole or fractional root of a number.

3.—What root or power any one given number is of another.

To understand clearly the methods of procedure, it will be necessary to refer to the construction of the common slide rule, upon which this apparatus is based.

With the ordinary rule the arithmetical operations of multiplication and division are performed by the addition and subtraction of the logarithms of the numbers operated upon. As for instance, in multiplying A by B, the logarithm of B on the sliding part is mechanically added to the logarithm of A on the other scale, and the length, as it were, of these two logarithms together is equal to the length of the logarithm of their product. Thus log. A + log. B = log. (A × B), and so with division, the difference between the logarithms of the numbers being equal to the logarithm of the quotient, thus log. A — log. B = log. (A ÷ B). When it is required to raise a number to a different power, scales of different lengths are employed, the lengths of the respective scales being in the ratio of the power required to unity. This condition arises from the fact that the logarithm of the nth power of a number is n times the logarithm of the number itself. Thus we might read off the values of x^2 on a scale $\frac{1}{2}$ the length of the scale of log. x, or the values of $D^{\frac{2}{3}}$ on a scale $1\frac{1}{2}$ times the length of the scale of log. D; or we might read the values of $V^{\frac{10}{9}}$ upon a scale $\frac{9}{10}$ the length of the scale of log. V.

It will thus be evident that the use of mechanical logarithmic calculations could be much extended by the adoption of a combination of scales which might be altered to any mutual ratio at will.

This end may be reached in at least two ways:—

1.—By drawing lines radiating from a centre to each division on one scale, and causing the second to slide across parallel to the first scale, so as to intersect the radiating lines at any required length. (See Plate XV.) This method is open to the objections that there is a difficulty in ruling the lines correctly, and that towards the centre they become too close together.

2.—By ruling a series of parallel lines at distances equal to the spaces on the 1st scale, and allowing the other to slide radially over these lines, so that the vertical height of the one may bear any desired ratio to the vertical height of the other. (See Plate XVI.)

The apparatus used by the writer consists essentially of such a logarithmic scale extended up to four divisions, or 10^4, carefully ruled by hand upon paper glued to a board. At one end of the board are marked the corresponding real numbers, and at the other are scales of equal parts, for reading off the different powers or roots. This scale may be easily made by pricking off the divisions from an ordinary slide rule. The movable part is a plain logarithmic scale of such length as will embrace the whole scope of the instrument. For certain purposes a plain slip of paper will serve instead. For large powers of numbers, under 30 or thereabouts, a movable scale is used, in which each division is four times the length of the divisions upon the ruled board. This proportion is also convenient for fractional indices between $\frac{1}{2}$ and $\frac{1}{4}$, when no multiplication or division of numbers is to be effected at the same time. For combined operations of multiplication and evolution, it is most convenient to use a movable scale in which the divisions correspond with those on the board. This proportion is also most convenient for powers between $\frac{1}{2}$ and 2.

The uses of the apparatus above described will be best understood by a few examples of problems which might occur in everyday practice.

The construction of Rankine's adiabatic curve, $PV^{\frac{1.0}{9}} = C$, for which the apparatus was originally designed by the writer, will serve as one type.

The ordinary method of procedure is, of course, to obtain the $\frac{1.0}{9}$ths power of each different volume by means of a table of logarithms. The calculation is one which involves a good many figures and a good deal of mental labour. For purposes of comparison the calculation is given below.

Let $P = 160$, $V_1 = 1$, then $C = 160$, and for any ordinate,

$$\log. P = \log. 160 - \tfrac{1.0}{9} \log. V.$$

Log. P_1 = 2·2041200		
log. 1·5 V	= ·1760913	2·2041200
„ $\times \frac{1.0}{9}$	= ·195657	·195657
		2·008463
	= log. 102.	
Log. 2 V	= ·3010300	2·2041200
„ $\times \frac{1.0}{9}$	= ·334477	·334477
		1·869643
	= log. 74·07.	

Log. 2·5 V	= ·3979400	2·2041200
„	$\times \frac{1}{9}^0$ = ·442155	·4421555
		1·7619645
	= log. 57·8	
Log. 3 V	= ·4771213	2·2041200
„	$\times \frac{1}{9}^0$ = ·530134	·530134
		1·673986
	= log. 47·2.	
Log. 3·5 V	= ·5440680	2·2041200
„	$\times \frac{1}{9}^0$ = ·604520	·604520
		1·5996000
	= log. 39·78.	
Log. 4 V	= ·6020600	2·2041200
„	$\times \frac{1}{9}^0$ = ·668955	·668955
		1·5351650
	= log. 34·29.	
Log. 4·5 V	= ·6532125	2·2041200
„	$\times \frac{1}{9}^0$ = ·725791	·725791
		1·4783290
	= log. 30·08.	
Log. 5 V	= ·6989700	2·2041200
„	$\times \frac{1}{9}^0$ = ·776633	·776633
		1·4274870
	= log. 26·76.	
Log. 5·5 V	= ·7403627	2·2041200
„	$\times \frac{1}{9}^0$ = ·822625	·822625
		1·381495
	= log. 24·07.	
Log. 6 V	= ·7781513	2·2041200
„	$\times \frac{1}{9}^0$ = ·864612	·864612
		1·3395080
	= log. 21·85.	

Log. 6·5 V	= ·8129134	2·2041200
„ × $\frac{10}{9}$	= ·903237	·903237
		1·300883
	= log. 19·99.	
Log. 7 V	= ·8450980	2·2041200
„ × $\frac{10}{9}$	= ·938997	·938997
		1·2651230
	= log. 18·41.	
Log. 7·5 V	= ·8750613	2·2041200
„ × $\frac{10}{9}$	= ·972290	·972290
		1·2318300
	= log. 17·05.	
Log. 8 V	= ·9030900	2·2041200
„ × $\frac{10}{9}$	= 1·003433	1·003433
		1·200687
	= log. 15·87.	
Log. 9 V	= ·9542425	2·2041200
„ × $\frac{10}{9}$	= 1·060269	1·060269
		1·143851
	= log. 13·92.	
Log. 10 V	= 1	2·2041200
„ × $\frac{10}{9}$	= 1·1111	1·1111111
		1·0930089
	= log. 12·39.	

The last two half-volumes have been omitted, as the difference between the calculated pressures becomes small.

The mechanical method used by the writer may be described as follows:—A strip of paper is cut with a straight edge, long enough to cover the top and bottom lines of the board. The vertical distance between these lines is then marked on the strip. The bottom mark is placed on the bottom line, and the strip is inclined towards the base until the distance of the top mark from the bottom line is $\frac{9}{10}$ths of the whole

height, judged by the scale of equal parts drawn on one side of the board. Then accurate marks are made where the logarithmic lines 1, 1·5, 2, 2·5, 3, 3·5, 4, 4·5, etc., corresponding to the values of V_1, $V_{1\cdot5}$, V_2, etc., cross the movable strip in its inclined position. These new spaces will represent to scale $\frac{1}{9}^0$ log. V_1, $\frac{1}{9}^0$ log. $V_{1\cdot5}$, etc. All that remains to be done, therefore, is to return the strip to a vertical position, place each mark in turn upon the line of 160, and read off at the bottom mark the pressures derived from subtracting $\frac{1}{9}^0$ log. V from log. 160. The operation will thus be seen to be excessively simple, only occupying a few minutes' time, and possessing as much accuracy as is usually required in calculations of this kind.

The converse operation of analysing a given expansion curve of this class would be as simple. Starting with the necessary data of P_1 and V_1 we obtain C, thus—

$$\frac{P_1}{V_1^x} = C, \quad \text{or} \quad V_1^x = \frac{P_1}{C}.$$

The strip of paper is taken as before and marked at the extremities. The bottom mark is placed on the observed value of P_2 or P_n, and the distances of that series of lines from C are marked on the strip. The bottom mark of the strip is then placed upon the bottom line of the board, and the strip inclined off the perpendicular until the mark in question comes to the line of 1·5, 2, 2·5, etc. Then the cosecant of the angle of inclination, or the ratio of extreme length to projected length upon the scale of equal parts, is the value of the index of V. Thus, if the strip had to be inclined to $\frac{16}{17}$ of its original height, before the mark corresponding to V_2^x coincided with the line of V_2, then it is shown that at this part of the curve—

$$P \propto \frac{1}{V^{\frac{17}{16}}}.$$

Another simple case of avoiding the use of logarithmic tables might be shown with the formula given by Mr. R. L. Weighton, in the Transactions of this Institution, connecting the weight of a boiler with its pressure and heating surface. Here it is only necessary to obtain a constant from actual practice, then incline a scale until its projected height is equal to $\frac{5}{12}$ of the whole length, and note the value of $P^{\frac{5}{12}}$. The solution of formulæ like that of Unwin's, for the collapse of boiler flues,

$$P = 9{,}614{,}000 \frac{t^{2\cdot21}}{L^{0\cdot9} D^{1\cdot16}}$$

may be aided in the same way by this apparatus.

A more interesting case may be found when the index of one factor is variable. Suppose, for instance, that owing to some cause we had a right to expect, in a particular engine, that the normal pressure would rise gradually towards the end of the expansion, say from the constant $PV^{\frac{7}{6}}$ to $PV^{\frac{17}{16}}$, the index gradually changing as the expansion progressed.

To find this curve by calculation is a somewhat more involved process than the previous one. Taking a proportional part, say $\frac{1}{10}$ of the difference between these indices, and substract this successively for each ordinate:—Thus—

$$PV^{\frac{7}{6}} \text{ to } PV^{\frac{17}{16}} = C.$$

$$d = \cdot1041; \quad \frac{d}{10} = \cdot0104.$$

1st ordinate $C = PV^{1\cdot1666} = PV^{\frac{7}{6}}$.
2nd „ $C = PV^{1\cdot1561}$.
3rd „ $C = PV^{1\cdot1457}$.
4th „ $C = PV^{1\cdot1353}$.
5th „ $C = PV^{1\cdot1249}$.
6th „ $C = PV^{1\cdot1145}$.
7th „ $C = PV^{1\cdot1041}$.
8th „ $C = PV^{1\cdot0937}$.
9th „ $C = PV^{1\cdot0833}$.
10th „ $C = PV^{1\cdot0729}$.
11th „ $C = PV^{1\cdot0625} = PV^{\frac{17}{16}}$.

Having obtained these indices we proceed as before to multiply the logarithm of each successive volume by its own index, and to find the logarithm of the pressure by subtracting this quantity from the logarithm of the initial constant. By the mechanical method, however, the amount of calculation is reduced to zero.

On the face of the board we draw a straight line from the value of $\frac{7}{6}$ to that of $\frac{17}{16}$, as shown by the scale of powers at the side. (On Plate XVI. the line is drawn from $\frac{7}{6}$ to $\frac{10}{9}$.) This line is divided and marked into 10 equal parts. Then, instead of the movable strip of paper being kept in one position while the logarithms of the volumes are marked, the upper end of it is shifted from spot to spot for each volume, along the divided index line. When these are marked, the pressures are read off as before by using the marked strip upon the board as if it were the slide of an ordinary slide rule; or, in other words, by placing each mark in turn upon the line of the initial constant, and reading off the pressures at the bottom mark, the strip being now not in an inclined but a vertical position.

The converse process of laying down a graphic index from an existing curve will easily present itself to the minds of those who have grasped the principles of the methods described in the foregoing paragraphs.

While the occurrence of variable indices is before us it may be as well to notice that the question of steamship propulsion offers a practically inexhaustible field for investigation in this direction, and the writer ventures to express the hope that a future generation of naval architects may find it in their power to use variable indices, influenced by known laws, instead of the anomaly of a "variable constant" for one ship, at present in use.

As an example of this nature, the supporters of Mr. Mansel's theory of propulsion will be interested in the employment of graphic aid in their calculations. Taking Mr. Mansel's fundamental formula in its most recent form, $E = D^{\frac{3}{5}} V\ 10^{(V-X)a}$ in which X is a certain fixed speed for each vessel, we observe that the index of 10 is of the form $y = m V + C$, which is the equation to a straight line. If, therefore, two extreme values of this index be taken and noted upon the ruled board, intermediate values may be found without calculation by dividing the line joining these spots into the required number of equal parts, when each division will represent an index. Or the line may be produced both ways, and the powers for untried speeds determined, so long as we can rely on the index remaining a straight line. But, as Mr. Mansel has pointed out, it may be crooked. Should the true speed curve of a vessel be found to contain an undulating factor, as may be seen in the speed curve of the "Merkara's" model (see *Transactions of the Institute of Engineers and Shipbuilders in Scotland*, Vol. XXVIII.), the graphic index of this factor might be laid down upon the board as the generating circle of a wave line or as an ascending wave line. An exaggerated curve of this form is shown in Plate XVII. In this case the variation of the index is so great as to cause a decrease in the ordinate, even with an increased factor.

A further use to which the mechanical calculation of curves may be extended is the determination of the maxima and minima of quantities, such as weights, efficiency, or costs.

As an example, a formula has been obtained by Mr. W. J. Millar, C.E., by means of which may be decided the most economical speed at which to drive a steamer, in relation to the cargo carried and the coals consumed. Mr. Millar gives two expressions, one representing the value of the cargo, the other the expense of carrying it, the difference representing the available profit. Thus, assuming the power to vary as speed^3, we have:—

C = total carrying capacity,

S = length of voyage in knots,

K and m = factors connecting the coal consumption and horse-power,

then— $$\frac{C\,V}{S} - K\,(m\,V^4) = \text{profit.}$$

By the aid of the differential calculus we may find the most economical speed to be— $$V = \sqrt[5]{C \div 4\,K\,m\,S.}$$

Graphically it may be found by drawing the line $\frac{C\,V}{S}$ from a given origin, and the curve $K\,(m\,V^4)$ from the same point.* The speed we are seeking is at the point where the vertical distance between the two lines is greatest. Where they cut, profit ceases. If the speed is increased to a point where the lines have crossed, we understand that the value of the coals consumed is greater than the value of the cargo. (See Plate XVIII.) But if the power does not vary as the cube of the speed, say from $V^{2\cdot8}$ to V^4, the value of the graphic method is more apparent, all that requires to be done being to lay down the graphic index on the board and proceed as already indicated.

In conclusion, the writer can only express the hope that these few examples will serve to indicate the nature and scope of an apparatus which a moderate amount of care will enable anyone to make and use for himself.

DISCUSSION.

Mr. JAMES THOMSON, Jun., in opening the discussion, said this paper was very interesting, and the graphical method shown was very ingenious, but he did not know whether it would be very useful. One difficulty in regard to the diagram was, that for accurate work the lines on it would require to be drawn with a much finer subdivision than that indicated, and it would then be practically impossible to take the readings on account of the difficulty of tracing the lines along to the scale at the end. That was one difficulty that struck him at the outset. Then he thought Mr. Young had exaggerated the difficulty of using logarithms in comparison with the graphical method. Mr. Young's diagram was very good if there were a great deal of work of the same kind to be done; but if such work only occurred occasionally, it would scarcely be worth while to lay out that careful ruling. He did not know that, for practical purposes, it would often be wanted. They required indices certainly, sometimes, but not as Mr. Young suggested, in calculating speeds of ships. Mr.

* For Mr. W. J. Millar's paper, see Proceedings of the Edinburgh Mathematical Society, Session 1888–89.

Mansel's method was not really of much practical use; so he (Mr. Thomson) did not quite see for what useful purpose one would use this scale. Then he noticed, in the example Mr. Young gave of logarithms, he took the ordinary tables, such as Chambers's, with seven figures; that was more than necessary. They could get tables of logarithms up to four figures, the whole table being on one page; so that there was no need to turn over pages. When they had logarithms such as these the calculations were much simpler than Mr. Young showed in his paper, and there was less reason for graphical methods.

Mr. J. C. STIRZAKER said he would like to ask Mr. Young a question as to his method of investigating curves. The other day he (Mr. Stirzaker) wished to obtain the equation to a rather peculiar curve.

A MEMBER—Could you write the equation on the board ?

Mr. STIRZAKER—I have not discovered it. It varied irregularly, increasing, at first rapidly, afterwards slowly, from the 1·85 power to the square. Was Mr. Young's method capable of determining the equation to such a curve ? If so, it was very valuable. He thought, with Mr. Thomson, that for regular curves one would prefer to use logarithms ; but for varying curves, the saving by this system appeared considerable. It must, however, be a rather rough way of working. Calculating to two or three places of decimals would give more accurate results. The method was very ingenious, and he thought Mr. Young deserved great credit for his ingenuity, and for the trouble he had taken with the paper.

Mr. THOS. PHILLIPS (of Lloyd's Register) said he had followed the reading of this paper with a considerable amount of interest, and quite admired the ingenuity and mathematical skill displayed in the production of the paper. He thought that although there might be difficulties in the readings as pointed out by a previous speaker (Mr. Thomson), yet on the whole it was of great practical use in reading and interpreting curves. He thought the writer, with the mathematical skill which he evidently possessed, would have no difficulty in altering his diagram to obtain the equation sought by the last speaker (Mr. Stirzaker). He desired to express his appreciation of the paper, and that most heartily. A paper of this kind, although it might not appear to those not mathematically inclined to be of very much advantage, yet they knew that the whole art of shipbuilding and engineering was governed by mathematical science. Personally he thanked the writer of the paper, and he thought he echoed

its of all present.

The VICE-PRESIDENT, having failed to obtain any other speaker on the paper, said that according to their usual rule the discussion would stand adjourned; but it was desirable, so far as possible, that all the business of this meeting should be completed, he could now only call upon Mr. Young to reply to the discussion. He was sorry that a paper which had evidently such a wide field before it, and offered in its applications such a wide scope for debate, had not called forth more opinions. He thought the "mechanical aid" would be useful in a great many ways. There were times when tables of logarithms were not to be got so very handy, and one or two scales such as had been exhibited might be very usefully applied. Things nowadays had a tendency to be rushed, and there was not so much time to be given to mathematics on everyday subjects in ordinary business. He was sure they had in this paper a very important field for research and exploration, and for himself he must say he very much appreciated what had been put before them. The examples given to them were not principles, but simply illustrations. Each one could adapt the system to his own requirements. Some people did not care about the sliding rule, partly because they did not think it was necessary, and partly because it was not thoroughly understood; and probably this arrangement, if more closely studied and practised, would be found more useful than appeared at first sight. It came before them in a somewhat unfamiliar aspect, and they did not, as a rule, take in such ideas very quickly. He had now to call upon Mr. Young to reply to the discussion.

Mr. J. D. YOUNG, in reply, said that with regard to Mr. Thomson's remarks, an apparatus of this kind was, of course, chiefly of use for special purposes. There were, doubtless, many cases in which the use of logarithmic tables was preferable or necessary, but there were other occasions, such as the analysis of long enumerations of experimental data, when the application of a graphic or a mechanical method would not only be a mental relief to the investigator, but might direct him to the nearer solution of the questions in hand. There was no difficulty in reading the lines of a fully divided scale when every tenth one was made thicker than the ones between; and the apparatus once made, it was always as ready for use as a table of logarithms. Mr. Mansel's theory was merely given as an illustration of a method of working, not as a theory which he (Mr. Young) was prepared to accept as correct or complete. But what he wished to lay most stress upon was the value of a graphic index in showing the tendencies of the natural laws involved, and showing them in a way in which columns of figures could not do.

With regard to the question put by Mr. Stirzaker, Mr. Young said that in the investigation of an unknown curve considerable judgment must be used. There might or there might not be some *à priori* reason to suspect the existence of a variable index in the particular case in point, and when there were more than one factor involved, those that could not be affected by a variable index would have to be removed first. He would recommend Mr. Stirzaker, after taking these precautions, to draw a series of equally spaced vertical lines across the apparatus and mark upon each line in succession the value of the index, as explained in the paper, when it would be seen at a glance whether the spots lay in the form of any known curve, if not in a straight line. He thanked the speakers for their kindly appreciation of his paper, and trusted that it would be found useful to some members in their work.

The VICE-PRESIDENT said he could not be wrong in assuring Mr. Young of their appreciation of his labours, and he called upon them to return him their very warmest thanks.

The vote was accorded by acclamation.

ADJOURNED DISCUSSION ON "THE UNSINKABILITY OF CARGO-CARRYING VESSELS."

Discussion was resumed on Mr. W. Hök's paper on "The Unsinkability of Cargo-Carrying Vessels," read at a former meeting.

The SECRETARY (Mr. Duckitt) intimated that he had received a communication from Mr. L. Piaud, Inspector-General to the Bureau Veritas in Paris. He could not speak as to its character, as he only had had time to glance at it.

The VICE-PRESIDENT said that seeing it was a written communication it might be well to have it perused by some member of the Reading Committee before being read to the meeting, and, practically, made public. They did not know but what it might involve complications of which they were not aware; and reading a lengthy communication in this way might be rather awkward, even although it was the writer and not the Institution who would be responsible.

The SECRETARY—From glancing over it, it seems to me only a question in regard to certain rules made by Veritas.

Mr. R. L. WEIGHTON—I would propose that the paper be read.

Mr. J. R. FOTHERGILL—I second the proposal. I see little difference between reading a written and signed communication and making remarks personally from the platform. In each case it is the person's own opinion.

The VICE-PRESIDENT having put the resolution to the meeting, the proposal was adopted without dissent.

COMMUNICATION FROM MR. L. PIAUD.

PARIS, *January 7th*, 1891.

This very interesting paper will certainly prove to be useful in illustrating the dangers to which shipowners are exposed on account of the defective arrangement of water-tight bulkheads. It will be readily admitted that the registration societies have always been aware of the necessity of requiring a more complete partition of vessels, but that they naturally meet with strong objections on the part of owners who contend that too many bulkheads would interfere with their commercial interests. These objections are certainly justified in many instances, but it is not always so, and I strongly believe that if owners were well persuaded of the enormous danger to which their property is constantly exposed, it would be possible

to lead them to secure sufficient safety without interfering with trade in the great majority of cases. If very long holds are required for carrying woods or other cargoes of great length, a central longitudinal bulkhead might be fitted without any inconvenience; in other cases, a proper arrangement of hatches might allow of very large pieces of cargo being shipped in holds far smaller than they generally are. But to obtain such a result some goodwill should be required from all parts.

The Bureau Veritas has endeavoured for many years to induce owners and builders to fit as many water-tight bulkheads as were needed to render vessels practically unsinkable. In article 2 of their rules it is said that "steel or iron vessels which are divided in a sufficient number of water-tight compartments to keep the vessel afloat in case of a serious leak in one of the said compartments shall be inserted in the register book with the mark 'O.'" To obtain this distinctive mark a maximum load-line beyond which the vessel shall not be loaded must be submitted for the approval of the Bureau Veritas, also a complete plan of the various compartments, together with the calculations of the displacement and *of the longitudinal and transverse stability, supposing one of the compartments to be filled with water.*

Many mail and passenger steamers have received the above mark, and also a few cargo vessels, and it may be said that this departure has proved to be quite successful.

Vessels built according to the above rule are indeed practically unsinkable, because not only their buoyancy but also their stability has been ascertained previous to the approval of the plans.

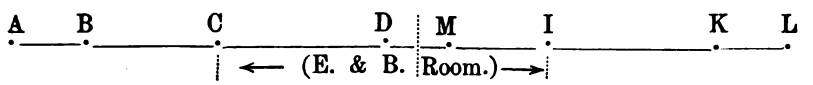
Some further steps have been taken by the Bureau Veritas to obtain a gradual increase in the number of water-tight bulkheads. Article 23 of the rules provides that "intermediate bulkheads must be fitted in holds of steamers whenever their length exceeds 90 feet." If this rule is compared with those enforced by Lloyd's Register, it will be seen that the Bureau Veritas has an advantage over the latter; and it may be assumed that if Mr. Hök's calculations had been made on vessels built according to Veritas' rules, the limit of unsinkability for various classes of steamers would have been lowered.

To show the accuracy of the above statement, let us compare the regulations of both societies, under the assumptions of Mr. Hök with regard to the length of engine and boiler rooms, as well as of fore and after-peaks, in relation with the total length of vessels.

Besides the four fundamental bulkheads, Lloyd's rules require :—

1 additional bulkhead for vessels over 280 feet.
2 ,, ,, 330 ,,

Bureau Veritas rules require one additional bulkhead in any compartment exceeding 90 feet. Let us see, first, beyond what length of a ship does the length of a hold exceed 90 feet, according to Mr. Hök's assumptions:—



I. *Fore-hold.*

$$IK = ML - KL - MI = \frac{l}{2} - 0{\cdot}08l - \left(\frac{\frac{l}{10} + 15'}{2} - \frac{l}{100}\right) = 90'.$$

Hence $l = 217$ feet.

Thus, one additional bulkhead is required by Bureau Veritas in the fore-hold of vessels when length exceeds 217 feet, against 280 as per Lloyd's.

II. *After-hold.*—In the same manner, it will be found that—

$$BC = AM - AB - CM = \frac{l}{2} - 0{\cdot}08l - \left(\frac{\frac{l}{10} + 15'}{2} + \frac{l}{100}\right) = 90'$$

$l = 229$ feet.

An additional bulkhead in after-hold is required by Bureau Veritas in vessels exceeding 229 feet in length.

III. Another additional bulkhead is required in the fore-hold if the length of same exceeds 180 feet, which corresponds to a length of vessel equal to 418 feet, and so on.

Hence the following table can be drawn up :—

Length of Ship.	Additional Bulkheads.	
	Lloyd's.	Veritas.
Feet.		
Under 217	0	0
217-229	0	1 in fore-hold
229-280	0	2 (1 in fore-hold, 1 in after-hold)
280-330	1 in fore-hold	2 *id.*
330-418	2	2 *id.*
418-440	2	3 (2 in fore-hold, 1 in after-hold)
Over 440	2	4 (2 in fore-hold, 2 in after-hold)

Sailing Vessels.—This is the most disgraced class of vessels; and, indeed, no reason can be given for the total want of bulkheads in them but the bad routine which has prevailed from the time of wooden vessels. To try and fight against it the Bureau Veritas has again made a new departure in the rules just published. One water-tight bulkhead amidships is recommended in sailing vessels of 250 feet length, and two bulkheads in vessels of 300 feet. Besides that, a special mark ☐ is granted to iron or steel sailing vessels fitted with so many water-tight bulkheads (besides the collision bulkhead) that each mast may be placed in a separate compartment.

We hope that the value of this mark will be duly appreciated by shipowners and underwriters, and lead to an efficient protection of sailing vessels against all dangers of collision.

L. PIAUD,
The Inspector-General of Bureau Veritas.

Mr. A. LECKIE said he had not read Mr. Hök's paper, and it was only from the remarks brought out in the letter just read that he was induced to speak. So far as unsinkableness was concerned, it struck him that, even with the bulkheads fitted as ordered by Veritas, they still came a long way short of the unsinkable craft. That very vessel [pointing to a framed photograph of the "Clio," of Hull, on the platform], after she was repaired, laden with a cargo of pig iron, and sent to sea, sank in five minutes after having been struck on the bulkhead between Nos. 3 and 4 holds, going down stem foremost; and nineteen hands were drowned. It was evident they must take care that the number of bulkheads should be increased, so that if one was struck, and the two compartments were full of water, the vessel would still have sufficient buoyancy to be safe. That was not a condition of safety in any craft he knew. When acting for the Board of Trade, he drew their attention to the distance of bulkheads in passenger steamers not giving safety; but the reply was, "in this case you may allow them to pass." The third point was the strength of the bulkheads. He had not seen any bulkheads made, either under Lloyd's, Veritas, or other classification, that was equal to the pressure that came upon them when one of the holds was filled with water—that is, when one compartment was filled; it was the additional weight or displacement that caused the ship to sink down. It was with such additional pressure that the bulkheads in many cases gave way. Practically, for the bulkheads to be of any use they would require to be strengthened in such a way as to be able to stand the pressure of water, presuming the vessel to be full up to the main deck.

Mr. J. R. FOTHERGILL regretted he was not able to agree with his friend Mr. Leckie on the question of bulkheads. No doubt they could so subdivide a cargo ship by water-tight bulkheads that the filling of any two compartments would not materially affect her; but he (Mr. Fothergill) was of the opinion such subdivision would so interfere with the carrying, loading, and discharging of the cargo, that commercially such a vessel would be a failure, for she could not be sailed to profit. He thought the shipowner was perfectly justified in his contention that the present number and arrangement of bulkheads was quite sufficient. Undoubtedly there was a certain amount of risk from collision and similar causes; but was not that so in all undertakings? The proper remedy was to remove the danger, and not to construct a vessel to be proof against such contingencies—invariably the outcome of negligence and carelessness.

Mr. A. MCGLASHAN, being called upon, said he could not pretend to give an opinion on the paper; there were many important points in it, but he had not been able to read it thoroughly. He did not think, however, that it was assumed by Lloyd's or shipbuilders or shipowners that the present rules for the arrangement of bulkheads would make ships unsinkable under the conditions assumed in the paper. He thought with Mr. Fothergill that the difficulties of shipowners were already sufficiently numerous without adding to them by requiring bulkheads to be placed close enough in vessels to make them unsinkable. He did not see anything mentioned in the paper regarding the value of double bottoms in ships as contributing to their unsinkability, though frequently very considerable damage has been done to the outer bottoms of ships and their safety still maintained because of the efficiency of their inner bottoms. He should not say more lest he should be doing an injustice to the writer of the paper. There was a great deal of matter in it, and probably altogether valuable, although he was not in a position to say so.

Mr. T. PHILLIPS said he could plead the same excuse as the previous speaker, he had not had an opportunity of studying the paper. There seemed to be a lot of matter in it, and a lot of assumption. Several of the assumptions he thought might be avoided altogether, and something of a more definite character stated. For instance, if he understood the paper, it seemed to him slightly out of order to assume that the hold should be perfectly full of water, completely filling it up to the beams, while the ship would be floating with a considerable part of the deck out of water. In regard to the treatment of the question of the unsinkability of ships, he thought he should prefer the manner it had received attention

from Mr. Barnes and Mr. Dunn, both gentlemen connected, or lately connected, with the Admiralty. Mr. Barnes, in a very scientific paper of an exhaustive character, treated the case of the different compartments separately. He (Mr. Phillips) did not know whether the results shown in this paper were the same as those of Mr. Barnes, but on account of the difficulties in connection with the subject, he really thought it was an utter impossibility to treat it satisfactorily in any other way than that done by Mr. Barnes. This paper, however, showed a great deal of ingenuity and mathematical skill. With reference to what had been written by the Inspector-General of the Bureau Veritas in Paris, unfortunately he was not so familiar with the rules of Veritas as he was with the rules of Lloyd's. Possibly if there had been anything to be gained he might have taken an opportunity of studying what the rules of the Bureau Veritas really were. He had casually seen their book of rules, and no doubt it had been compiled with care, thought, and proper consideration of all the matters connected with the subject of shipbuilding; and he knew sufficient of the surveyors of Bureau Veritas to have confidence in their practical skill and integrity; but at the same time he thought, although he might be wrong in this respect, that it was hardly the thing to write and disparage other registers, if he might so put it, before an Institution of this kind. He (Mr. Phillips) had in his mind's eye the case of a steamer that was to be built somewhere in the vicinity of West Hartlepool. The drawings were submitted to Lloyd's Register, and in connection with the question of bulkheads, Lloyd's Committee refused to entertain the claims of the steamer for classification, because the bulkheads were not carried up sufficiently high, and he thought the height of bulkheads had a very important bearing on the efficiency of the structure. They were quite inefficient unless carried up, at any rate, above the waterline, for if one compartment is filled and the water gets above that bulkhead, naturally there is a passage into the next compartment and then two compartments would be turned into one, and hence the danger pointed out by Mr. Leckie. However, he understood the ship with these bulkheads, as first proposed, was eventually classed by Bureau Veritas. There was a vessel to be built, too, not a 100 miles from West Hartlepool, to be classed by Bureau Veritas, with six bulkheads, being exactly the same number as under Lloyd's rules. The bulkheads might be in the Veritas' rules in the form of recommendations, but were they in the ships? It was very good to have more bulkheads, but from the commercial difficulties alluded to by previous speakers, some great pressure would have to be put upon the registries, and assistance given

by shipowners, before they would find it possible to increase the number of bulkheads in ships, even although a greater number of bulkheads were desirable to make vessels unsinkable. In regard to the suggestion for having a longitudinal bulkhead, as pointed out by Bureau Veritas, it would be very useful in the way of giving the vessel longitudinal and vertical strength, but in the case of a vessel receiving damage, there might be in consequence a dangerous inclination to one side, and it was very questionable if a longitudinal bulkhead, to prevent foundering, would be as useful as bulkheads put in in some other way. He (Mr. Phillips) desired to express his thanks to the members of the Institution for giving him an opportunity of making these remarks.

Mr. JAS. THOMSON, Jun., said he had gone through the mathematical portion of the paper in the Appendix, and he thought he had found one small mistake. In stating, immediately after equation (1), $v_1 = v + a\,(d_1 - d)$, Mr. Hök had assumed that the mean draught d_1 of the ship represented the depth of water in the hold. Now, if the hold in question was near one end of the ship the depth of water might be very much greater than the mean draught of the ship. While pointing out this mistake he would say that perhaps it would turn out to be of little importance practically. It would be utterly impossible to deal with this subject in the way Mr. Hök had done without making a great many assumptions. So far as he (Mr. Thomson) saw, he was justified in his assumptions, but that was a thing that must be verified by calculation. Direct calculation should be made from the lines of a ship of the effect of having one compartment bilged, and the result should be compared with Mr. Hök's curves. Mr. Hök did not say whether he had made such calculations and whether they agreed with his results. If they agreed with his method of calculation the next point would be, what is to be done with the results? From Mr. Hök's second paper promised to the Institution they would hear what he proposed in that respect. He (Mr. Thomson) would just say that if bulkheads were increased in number it would mean increased working cost to the ship, more hatches, more steam winches, and might involve an extra mast in some cases. There was one slight set-off as to cost—if there were more hatches the cargoes would be discharged and loaded quicker; but this despatch would not balance the extra cost. To add to the number of bulkheads would be to add to the difficulties of the shipowner, which are sufficiently serious now in face of foreign competition; but even if they did not recommend more bulkheads it was still important to know whether a ship was or was

not "unsinkable." No one supposed that a ship was absolutely safe when it went to sea; it was always a question of what was reasonable. Mr. Hök had asked four questions in this paper. He did not know whether anyone had answered them. They were:—(1) Are the formulæ used in the present investigation accurate enough for solving these problems? He (Mr. Thomson) thought they were, but that they should be tested by other calculations. (2) What should be the minimum freeboard, forward, middle, and aft, to ensure unsinkability? (3) What percentage of water should be supposed to be admitted in vessels built for general trading purposes in case of damage? He thought in regard to both these questions Mr. Hök's assumptions were reasonable. (4) Is it sufficient, in attempting to provide adequate subdivision, to assume that only one of the principal compartments is in communication with the sea? Clearly, to ensure safety the ship should be capable of floating with any two compartments in communication with the sea. This represents the case of a ship struck at or near a bulkhead so that the bulkhead is destroyed. Mr. Hök's paper must have necessitated a great amount of work in its preparation, and the Institution should be very much obliged to him for it.

The VICE-PRESIDENT said that, with regard to sailing vessels, there was a firm of shipowners on the Clyde who, some fifteen or twenty years ago, were in the habit of subdividing their sailing vessels—some 220 feet long or thereby—with four water-tight bulkheads. These vessels were employed principally in the East Indian trade. As the succeeding vessels became larger, they were found expensive and unhandy in working, and the extra bulkheads gradually disappeared; and for some years now the vessels built for this company had simply the ordinary collision bulkhead forward, and in a few cases another bulkhead close aft. There were difficulties in working, as had been very well remarked. It was a very difficult question to combine the desirable and the practicable; and as their worthy friends who loaded and discharged vessels were mostly agreed that, as the ships were just now, they required all the hatches, winches, and ventilation at present supplied, if further subdivision was carried out still more hatches, winches, etc., would be required; besides, the smaller, or rather shorter holds were not so convenient for general stowage. The difficulties of complying with these requirements was the case of bulkheads being gradually discontinued; and, not so much for the conveyance and stowage of materials of considerable length, such as timber or rails, as the great bulk of the cargoes was ordinary merchandise and Manchester

goods. He knew another case, some years ago, where a bulkhead subdividing the fore from the main hold in a small coasting steamer had, by some mistake, been partly fitted, and when the builder discovered they had gone so far with the bulkheads it was offered to the owner for a nominal sum; but he would not have it, as his experience of a previous steamer with this bulkhead had been such that he would rather pay money to keep the bulkhead out of the vessel. He would not call upon Mr. Hök to reply, as the discussion would be continued in Newcastle. He believed it was at his (Mr. Macoll's) instigation that the discussion had been resumed at the present meeting. He wished more of the members had taken part in it.

The discussion was then adjourned.

ADJOURNED DISCUSSION ON "INCREASED BOILER PRESSURE AND INCREASED PISTON SPEED FOR MARINE ENGINES."

The VICE-PRESIDENT said there was a communication from Mr. Cummins in reply to the discussion on his paper upon "Increased Boiler Pressure and Increased Piston Speed for Marine Engines." He gathered it was a paper of some two dozen pages of foolscap, and as they would all get it in due course in print, and they could read it at their own convenience—and also, as this meeting place was not, under existing circumstances, the most comfortable in the world—he put it to them whether they would occupy some forty or fifty minutes by the reading, or close the meeting forthwith.

Mr. DUCKITT said he had to apologise for Mr. W. R. Cummins not being present, as he could not get through from Scotland.

On the motion of Mr. JAS. PATTERSON, seconded by Mr. J. R. FOTHERGILL, Mr. Cummins's reply was taken as read.

The meeting then dissolved.

COMMUNICATION FROM MR. G. ARNISON, JUN.

December 24th, 1890.

DEAR MR. DUCKITT,—At the last meeting of the Institution there were so many matters of interest in the proceedings that I did not think it advisable to further protract the discussion on Mr. Cummins's paper. There are one or two points to which allusion might not be out of place.

First, Mr. Cummins advocates apparently the adoption of 250 lbs. pressure of steam and increased piston speed, but although in the comparative example of a triple expansion engine having steam of 150 lbs. working pressure and a quadruple expansion engine with steam of 250 lbs. working pressure he proposes to increase the normal revolutions from 65 to 100 per minute, not the slightest consideration is given to the propeller. No doubt Mr. Cummins may reply that his object was only "to raise a few questions as to the advisability of increasing (1) the working pressure and (2) the piston speed of marine engines, and to consider what type of engines and boilers would best suit these conditions." It, however, appears that, to have a practical result, the efficiency of the engine in *propelling* the vessel should, in all such enquiries, be one of the questions considered.

Secondly, in considering what is the best type of quadruple expansion engine Mr. Cummins pronounces in favour of the four-crank engine. There is no need to disparage the "four-crank" engine, but it is said that many makers appear to have had success with both two and three-crank quadruple expansion engines, and there has been at least one three-crank *six*-cylinder quadruple expansion engine constructed, viz., that for the screw yacht "Rionnag-na-Mara." Several three-crank four-cylinder engines have been constructed on the river Wear.

Attention in the discussion on Mr. Cummins's paper has been already drawn to Mr. Thos. Mudd's patent quadruple expansion engine with three cranks and four cylinders, but no mention has been made of Messrs. Fleming & Ferguson's patent quadruple expansion engines, of which forty-one sets have been completed or are nearing completion for thirty-six vessels. They are four-cylinder *two*-crank engines, but owing to the cylinders being on the same plane and a triangular connecting rod, etc., being adopted, they run as smoothly as four-crank engines. The working pressure of steam adopted in these engines has been generally 160 lbs., in one instance 170 lbs., and in the twin screw steamer "Duckenfield" 200 lbs. per square inch.

Thirdly, in connection with the designing of boilers Mr. Cummins proposes a considerable departure, believing that such a course is necessary in order to obtain a satisfactory boiler for 250 lbs. working pressure, alleging that at such a pressure difficulties will arise with the furnaces and the flat sides of the combustion chambers. These difficulties are not particularised, but probably the drawbacks anticipated by Mr. Cummins are not merely constructive details, but something involving the durability and continued safety of the boiler. Certainly it is possible to obtain reliable furnaces for a boiler 10 feet 6 inches diameter with 250 lbs. working pressure. With "Purves" ribbed flues, 33 inches diameter and plates only $\frac{5}{8}$ths of an inch thick, the Board of Trade allows a working pressure of 265 lbs. per square inch, and by the formula of Lloyd's Register as high a pressure as 281 lbs. per square inch is permitted. There are, as some of the speakers in the discussion pointed out, grave disadvantages attaching to Mr. Cummins's proposed marine boiler, so that it is unnecessary for further comment to be made.

No doubt some good will result from the reading and discussion of Mr. Cummins's paper, which certainly reflects considerable credit upon the writer, and must have necessitated considerable care and attention.

I am, Sir,

Yours faithfully,

GEO. N. ARNISON, Jun.

MR. W. R. CUMMINS'S REPLY.

Mr. CUMMINS, before replying to the discussion on his paper, wished to thank the President (Mr. Wigham Richardson), the Past-President (Mr. F. C. Marshall), and the members attending the last two meetings, for the kind way in which the paper had been received and criticised. The object of the paper was to bring before the members of the Institution the advantages of an increase of boiler pressure and of piston speed for marine engines. While the majority of the speakers were of opinion that an increase of pressure and piston speed was desirable, there was naturally a diversity of opinion as to the best type of engine and boiler to suit the new conditions. He (Mr. Cummins) would now endeavour to reply to the discussion in detail.

Mr. Hall-Brown was under a misapprehension as to the meaning of the formula given in the paper. He said that "the formula was merely meant to represent the losses during adiabatic expansion." The formula did not represent the losses, but the *gains* during adiabatic expansion. It merely gave the amount of steam which would (according to Rankine and other authorities) be liquefied in doing external work (*e.g.*, work against a moving piston) if the steam were expanded adiabatically. In the paper this condensation of steam had been called *liquefaction* to distinguish it from condensation under other conditions. The greater the amount of liquefaction under these conditions the greater would be the resultant economy, as the steam thus liquefied gave up its latent as well as its sensible heat to do external work. In making the comparison between compound and triple engines the formula had been used to give the amount of liquefaction in each case under the conditions as given, and from it the theoretical advantage of steam of 150 lbs. pressure over steam of 100 lbs. pressure was calculated, always supposing that the steam was working adiabatically. It might be argued that, under the conditions in which steam is used, adiabatic expansion is not possible, and therefore the conclusions will not be valid; but a few considerations will show that even if the steam does not expand adiabatically, the result, as far as relative economy is concerned, is not affected. Suppose we take, as before, 1 lb. of steam at 115 lbs. absolute pressure, and let it expand behind a moving piston to 8 lbs. absolute pressure, and assume that a quantity of heat is given to it which will prevent the liquefaction which would otherwise take place. This heat may be given to the steam either by superheating or by a steam jacket, or by heat stored up in the cylinder walls by initial condensation. Then at the beginning of expansion we have 1 lb.

of steam at 115 lbs. absolute, and at the end of expansion 1 lb. steam at 8 lbs. absolute, whereas, if the expansion had been adiabatic, we should have had at the end of expansion ·8563 lbs. steam and ·1437 lbs. water. The quantity of heat required to prevent liquefaction is equal to the latent heat of ·1437 lbs. water at 8 lbs. absolute = 141·723 thermal units. So that—

Heat received = Total heat of 1 lb. steam at 115 lbs. = 1216·974 thermal units + 141·723 = 1358·697 thermal units.

Heat rejected = Total heat of 1 lb. steam at 4 lbs. absolute = 1160·625 thermal units.

1358·697 — 1160·625 = 198·072 thermal units utilised;

which is practically the same result as in the case when the steam was expanded adiabatically. The slight discrepancy is owing to the fact that the pressure at the end of expansion is not the same in both cases. In the same way, for steam of 165 lbs. absolute pressure, and conditions as in paper, the quantity of heat required to prevent liquefaction is equal to the latent heat of ·17169 lbs. water at 6 lbs. absolute pressure = 170·874 thermal units.

Heat received = Total heat of ·99305 lb. steam at 165 lbs. absolute pressure = 1216·974 thermal units + 170·874 = 1387·848 thermal units.

Heat rejected = Total heat of ·99305 lb. steam at 4 lbs. = 1152·558.

1387·848 — 1152·558 = 235·29 thermal units utilised.

Heat utilised with steam of 115 lbs. pressure = 198·072.

$$\frac{235{\cdot}29 - 198{\cdot}072}{198{\cdot}072} \times 100 = 18 \text{ per cent. economy as before.}$$

Mr. Hall-Brown said that no account had been taken of cylinder condensation. This had been treated in the paper when considering the second alleged cause of the economy of the triple expansion engine. Of course the loss from cylinder condensation is the greatest source of loss against which we have to contend; but what the paper attempted to prove was that in passing from the compound to the triple expansion engine the admitted gain of 20 per cent. was not due to any special advantage the latter engine possessed in the matter of small initial condensation, but was due mainly to the increase of working pressure. This was borne out by the marine engine trials carried out by the Institute of Mechanical Engineers, referred to by Mr. Hall-Brown. The reason why the amount of condensation in the "Meteor" did not vary materially during the expansion was merely because the cylinders were jacketed. Unfortunately,

the amount of steam condensed in the jackets was not measured, so that the amount of heat given up to the working steam cannot be calculated. The cylinders of the "Fusi Yama" and "Colchester," on the other hand, were unjacketed, and, as would be expected, the weight of steam present at the end of expansion was much less than at the beginning of expansion. The amount of condensation during expansion was, in the case of the "Fusi Yama" 29·2 — 16·9 = 12·3 per cent., and in the case of the "Colchester" 47·3 — 28 = 19·3 per cent. The greater part of this was probably due to liquefaction and not condensation. If, as Mr. Hall-Brown maintained, initial condensation is such an important question when comparing the economy of the compound and triple expansion engine, why was it that the "Fusi Yama," with an initial condensation of only 16·9 per cent., was less economical than the "Meteor," with its initial condensation of considerably over 23 per cent.? and why was the "Colchester," with an initial condensation of 28 per cent. nearly as economical as the "Fusi Yama," with only 16·9 per cent.?

As regards the style of engine, the arrangement proposed was to put each cylinder directly over its crank. Each cylinder supported at the back by a cast iron column, and at the front by a wrought iron column. The eight valves would be at the back of the engine, over the condenser, and worked by two rocking shafts running on the top of the condenser. The two sets of valve gear (each set working its own rocking shaft) would be together in the centre of the engine, thus dispensing with a reversing shaft. As regards the diagram for estimating the cylinder ratios, it was merely intended to give some idea of what the cylinder ratios would be. Of course, before finally fixing the ratios in an actual engine, the effect of not only clearance spaces, but also of cylinder condensation, speed of steam through ports, capacity of receivers, etc., would require to be carefully estimated.

Mr. T. Westgarth had misunderstood the proposed arrangement of cranks. No. 1 crank is at right angles to No. 2 crank, No. 3 crank is opposite No. 1, and No. 4 is opposite No. 2. As pointed out by Mr. Patterson, the motion of the four-crank engine is just as smooth as the three-crank engine, the reason being that the crank shaft as a whole is balanced in any position. The reason why the furnace of the boiler illustrated in the paper was enclosed in a casing was to avoid putting the most important part of the structure, viz., the shell, in contact with the furnace gases, as the stresses, caused by unequal temperature, of different portions of the shell would probably be very severe. Mr. Westgarth's remarks on the anticipated trouble with the tube plates will be treated

when replying to Mr. Patterson. As suggested by Mr. Spear, some of the trouble may have been caused by bad workmanship. From Mr. Westgarth's remarks it would seem that some of the boilers had fire-brick combustion chamber *backs*. This, of course, would be certain to give trouble, as similar trouble has occurred in cases of ordinary double-ended boilers, when the fire-brick division between the two opposite furnaces has been carried too high.

In reply to Mr. Thompson, the propeller question had not been touched upon in the paper, as it was discussed last session in Mr. Hall-Brown's paper on "High Speed Engines for Cargo Boats." Regarding his question of the cranks, this had been referred to in the reply to Mr. Westgarth.

Mr. Fothergill maintained that the heating surface of the boiler illustrated in the paper will not be efficient, as none of it is exposed to the radiant heat of the furnace.

The result of the experiments carried out by Messrs. Graham and others have no bearing on Mr. Fothergill's argument. For instance, the experiments with the four tanks simply show that the heating surface of the first tank was most efficient, simply because the temperature of the gases was highest at that point, the efficiency of heating surface being proportional to some function of the difference of temperature between the gases and the water.

The President's question as to what would have resulted if the first tank had been removed was very pertinent. Mr. Fothergill was of opinion that if the first tank had been removed the second tank would have shown an increase of efficiency, but would not have reached the efficiency of the first tank; but there are no grounds for this assumption. Let it be granted, however, that the tube surface of the proposed boiler will not be as efficient as the surface it replaces. The heating surface of the furnaces and combustion chambers of the present type boiler, 13 feet 6 inches diameter by 16 feet long, would be about 350 square feet. Suppose this surface to be 50 per cent. more efficient than the tube surface in the proposed boiler. Then extra surface to be provided = 350 square feet = 65 tubes, which would increase the diameter of the boiler proposed from 10 feet 6 inches to 11 feet 3 inches. In advocating forced draught the intention was to burn the same quantity of coal per square foot of heating surface as in the present type boiler with natural draught, and also to design the furnace to act more as a gas producer, which result is more easily obtained by the use of forced draught.

Mr. J. M. Allan said there were many instances of cylinders of nearly

100 inches diameter running at over 100 revolutions. This may quite easily be the case. In the first place, the weight of the moving parts per square inch of piston in a cylinder of 100 inches diameter would be (initial pressure and stroke being the same) less than the weight of the parts for a 71 inch cylinder. The limit of speed depended upon revolutions, stroke, and weight of moving parts. If the weight of the moving parts were *nil* the revolutions could be infinite. Mr. Allan then said that at the end of the stroke only the dead-weight of the parts had to be overcome, as the motion at that point was *nil*. This, of course, is a mistake; and it is precisely because the velocity of the moving parts varies from *nil* at the end of the stroke, to a velocity of about $1\frac{1}{4}$ times that of the crank pin, at the middle of the stroke, that the pressure required at the end of the stroke to bring the parts to rest is 14 lbs. per square inch of piston, and not 7 lbs. as supposed by Mr. Allan. The only assumption made in the calculations is that the angular velocity of the crank pin is constant.

The work done during the first half of the stroke in accelerating the velocity of the moving parts from *nil* up to a velocity equal to $1\frac{1}{4}$ times that of the crank pin, is, of course, given out again during the second half of the stroke, and this work is done in the case considered by a force varying from *nil* at the middle of the stroke to 14 lbs. per square inch of piston at the end of the stroke. If this force is not balanced by admitting steam behind the piston, then the work will be done in straining the moving parts themselves.

Lieut.-Col. English pointed to the results of trials on the efficiency of the steam jacket, notably those carried out by the Institute of Mechanical Engineers. Can Col. English point out any trials on the steam jacket where the amount of water suspended in the steam has been actually measured? If this measurement is omitted, trials on the relative economy of steam jackets are quite valueless, especially as the "economy" is generally expressed in terms of water per horse-power. It is scarcely necessary to remind Col. English that some trials show no economy, and some a loss from the use of the steam jacket. The causes of "priming" are, to say the least, obscure, and a good instance of the results of priming in vitiating trial results occurred in the case of the Mechanical Engineers' trial of the "Tartar." Fortunately, a complete analysis of the chimney gases was made, otherwise it could not have been proved that any priming had taken place. Taking the case assumed in the paper, of the jacketed and unjacketed cylinders, it was intended to assume that the heat distribution would be the same for each stroke. Now,

Col. English said that supposing the 100 thermal units were put into the jacket, the initial condensation being thus prevented, and the surfaces being of course raised to the temperature of the entering steam, that this effect might last for several strokes, from which it would be inferred that Col. English's theory of the steam jacket economy is, that it keeps the cylinder walls dry, and that a small quantity of heat from the jacket will do this, *i.e.*, a small quantity of heat transmitted through the cylinder walls heats up the surfaces to the same temperature, as a much larger quantity of heat given directly to that surface will do. In the first place, the surfaces exposed to initial condensation must be brought to the same temperature whether a jacket is used or not, and this temperature must be equal to, or greater than, that of the entering steam, for if they were not brought to this temperature the piston would not move, as molecular motion will take place before motion of the mass. The molecules of steam on first entering a cold cylinder give up their motion, first to the cold surfaces, and produce heat motion in them. After the surfaces have been raised to the temperature of the entering steam, and thus no more heat motion can be given them, motion of the mass (*i.e.*, the piston) can take place. Thus, if the temperature of the surfaces is below the temperature of the entering steam no motion of the piston can take place. It would be analogous to trying to move the piston with a lever and no fulcrum. As soon as the surfaces reach the temperature of the entering steam the fulcrum is supplied.

The next question is, how can the dryness or wetness of these surfaces affect the amount of heat necessary to bring them to initial temperature? Suppose that, at the beginning of the stroke, the surfaces are covered with a film of water at the lower temperature. The entering steam will raise this water to its own temperature, and then heat will be transmitted through the film to the metal underneath. If the surfaces are dry a film will at once form and heat be transmitted as before.

Thus the amount of initial condensation should be the same in both these cases, except that in the first case an extra amount of heat will be supplied to heat the film of water assumed to be left from the last stroke. Going back again to the case supposed by Colonel English —viz., that 100 thermal units put in the jacket have prevented condensation, the surfaces being therefore raised to the temperature of the entering steam—what happens when the temperature of the steam falls by expansion? If there is to be an economy with the jacket arrangement the heated surfaces must not give up as much heat to the steam as the same surfaces at the same temperature would give up if

the cylinder had been unjacketed and the condensation had taken place on the surfaces themselves. Now if hot steam gives up its heat so readily and so quickly to cold metal it would appear reasonable to suppose that hot metal would give up its heat just as readily and just as quickly to cold steam, for if it did not it would follow that the layers of steam next the surfaces would be at a higher temperature than the body of the steam, that is to say, the pressure in the middle of the working steam would be less than the pressure at the surfaces. This is, of course, conceivable if the cylinder was sufficiently large and the revolutions sufficiently high; but in all cases occurring in practice it would appear reasonable to assume that the temperature of the working steam is practically the same throughout its mass. Now, if this is so the whole of the 100 thermal units given to the surfaces by the jacket will be given back to the steam either during the period of expansion or of exhaust, or of both, and the quantity of heat required to again bring the surfaces to the temperature of initial steam would be as before, 100 thermal units, in which case no economy would result from the use of the jacket. Now, it might be asked, is it possible for the working steam, under the assumed conditions, to absorb these 100 thermal units? First of all, it can take up the heat necessary to prevent liquefaction, but after that any other heat received will superheat the steam. Now, if superheated steam does not readily take up heat, then the jacket should, under the assumed conditions, effect an economy. Suppose, for example, that 25 thermal units were required to prevent liquefaction, and that, owing to the steam being superheated, it only took from the walls 50 thermal units; then for the next stroke only 75 thermal units would be required to bring the surfaces to the temperature of the initial steam, and the resultant economy would be 25 per cent. In the case of the non-jacketed cylinder, 100 thermal units stored in the walls would first prevent liquefaction and then re-evaporate the condensed water.

Taking these points into consideration, the statement in the paper as to the value of jackets should be modified to this, "that, under the conditions usually obtaining in marine engines, steam jackets are of no value economically." Of course, the case just considered is purely hypothetical. It assumes that a jacket can entirely prevent initial condensation, that it is only acting during the period of admission, and that the quantity of heat received by the walls is not the same for every stroke.

Now, in the first place, it does not appear possible in a marine engine to entirely prevent initial condensation by steam jacketing, so that the

condition of the working steam after cut-off will be practically the same, as regards its power of absorbing heat from the walls, whether a jacket is used or not.

In the case of the S.S. "Tartar," alluded to before, the total amount of steam condensed in the intermediate and low pressure steam jackets, under the very favourable conditions for transmission of heat from the jackets, was 4 per cent. of the total feed.

In the "Meteor," the least initial condensation, including jacket condensation, reached 19·8 per cent.; so that the initial condensation might have been, say 24 per cent. without a jacket. An increase of wetness from 20 to 24 per cent. could not appreciably increase the heat absorbing power of the steam, in which case the amount of heat given up by the cylinder walls, after cut-off, would be the same whether a jacket were used or not, and therefore the amount of heat to be supplied for the next stroke would be the same in both cases, and hence no economy would result from the use of the jacket.

The second assumption was that the jacket was acting only during the period of admission. Of course the jacket was acting during the whole double stroke; but this does not directly affect the argument when comparing the two systems; but a question arises here which ought to be considered. The heat utilised in any cylinder is the difference between the heat received and the heat rejected, heat being received during the time piston is doing external work, and rejected during the time piston is doing work on the steam. Now, it might happen, and probably often does happen, that a steam jacket transmits heat to the working steam during the exhaust period, and all heat thus transmitted is lost, as far as concerns the cylinder under consideration, as it comes under the head of heat rejected. If this takes place in any cylinder except the low pressure the only loss is that due to the loss of efficiency when the heat thus given up is degraded from the higher temperature of the jacket to the lower temperature of the exhaust steam; but in the case of the low pressure cylinder the heat thus transmitted would be entirely lost.

The third assumption was that the quantity of heat received by the walls was not the same for each stroke. This also does not affect the argument when comparing the two cases. It is probable that after the engine has made a few strokes the whole body of the metal of the cylinder, etc., will reach a certain temperature which will remain constant, and that the heat transferred to and from the working steam will only affect an extremely thin layer of metal. Then if the working steam remains in the same condition

the amount of heat given up by the walls after the point of cut-off will be the same for each stroke, and consequently the amount of heat given to the walls during admission will be the same for each stroke. If the heat distribution was to vary for different strokes it would be shown on the indicator cards and in the working of the engine, which is not the case.

To sum up, then, the loss due to initial condensation is measured by the amount of heat given up by the cylinder walls during the period of expansion and of exhaust. If a steam jacket can so modify the condition of the working steam as to render it less capable of absorbing heat from the cylinder walls, then an economy should result; but as under the conditions obtaining in a marine engine this does not appear to be possible, nothing can be gained by adopting a jacket, which in particular cases (*i.e.*, when applied to the low pressure cylinder and transmitting heat to the working steam during the period of exhaust) may be a cause of loss. The loss from jacketing the receivers might be emphasised here. Many triple expansion engines are now arranged with the intermediate steam chest surrounding the high pressure steam chest, that is, steam of boiler pressure is giving up heat to steam of considerably lower pressure, the loss being measured by the difference of efficiency of steam at the two pressures. It might, however, be argued that as the steam in the receiver is in this manner dried that it will not be able to absorb so much heat from the cylinder walls after it is cut off in the next cylinder, and that thus the loss from initial condensation will not be so great in that cylinder; but this does not appear probable under ordinary conditions. As regards Col. English's remarks on the effect of piston speed, there was no argument in the paper maintaining that reduced condensation would be obtained by an increase of piston speed *per se*. Initial condensation should depend upon at least three factors, viz., amount of surface exposed, weight of steam exposed to that surface, and temperature range of that surface; and it was assumed to be evident that if the weight of steam exposed to the above surface with the above temperature range for unit time were doubled, that, although the same amount of steam might be condensed, yet the proportion of steam condensed to gross steam used would be considerably less. The expression "piston speed" was used because the weight of steam exposed to a given surface per unit time can be increased either by increasing the stroke or by increasing the revolutions of a given cylinder, the gain, of course, being much more apparent in the case of increased revolutions.

Mr. Buckland said that the four-crank four-cylinder engine advocated

in the paper would occupy more space than the present three-crank triple. This is not so, as the revolutions have been considerably increased, and the cylinders thus decreased. The space occupied would probably be about the same for both examples. Referring to the boiler, Mr. Buckland said that the first 1½ or 2 feet of tube surface from the combustion chamber end is equal to all the rest of the tube surface put together in point of efficiency. Now, the heating surface of the first 2 feet of the tubes in the boiler shown in the paper is 948 square feet, whereas the heating surface of the first 2 feet of the tubes of a boiler of the present type, 13 feet 6 inches diameter, is only 790 square feet, so that the "efficient" surface is 20 per cent. greater in the case of the boiler described in the paper, a glance at the drawing of which would have shown that the shell plates are *not* exposed to the fire. Mr. Buckland said that the sphere is the strongest body known. This is quite true, a sphere being twice as strong as a cylinder of the same diameter. It is, however, more than twice as difficult to manufacture.

Mr. Patterson said that the tube heating surface of the boiler shown in the paper would be just as efficient as the fire-box surface of an ordinary boiler, and that this very fact would make it an impracticable boiler.

The boiler had been severely criticised by most of the speakers, but no one had pointed out that the tube plate of the boiler shown in the drawing was unduly pressed. As a matter of fact, it was not pressed to nearly the same extent as some tube plates in boilers fitted with forced draught, and working quite satisfactorily. Although forced draught had been advocated for this design, it was not intended to burn more coal per square foot of surface than under ordinary natural draught conditions.

The cause of leakage at the joint of the tube plate with the furnace and at the tube ends had been ascribed to various causes.

The President (Mr. Wigham Richardson), speaking of some cases which had come under his notice, thought the trouble might be caused by the tube plates being rigidly held at the circumference. This might be the case if the tube plate was severely overheated, but the greatest number of failures had occurred with tube plates comparatively free at their edges.

Leakage might also be caused by the expansion and contraction of the furnace. Whenever the doors are opened for firing a rush of cold air will enter the furnace, which will be thereby cooled, and will consequently contract. By the time this air arrives in the combustion chamber it will be heated, and so will not cause the lower row of tubes to contract

to the same extent as the furnace. The cooling of the furnace will, of course, be much more marked when using forced draught on the closed stokehold system. To show that this contraction is not a negligible quantity, take a furnace, say 6 feet long, and suppose that 5 feet of it is cooled down from the temperature of the water in the boiler to the temperature of the air entering the furnace—*i.e.*, from 360 deg. Fah. to 60 deg. Fah.

$$\text{Contraction} = 300 \times 60 \times \cdot0000007 = \tfrac{1}{8} \text{ in about}$$

This alternate contraction and expansion occurring every time the fire doors are opened must be taken up in the furnace itself if it be corrugated or in the radius joining the furnace to the tube plate. There can be no doubt that it is this expansion and contraction of the furnace which first starts the tube plate joint and the tube ends. It is very clear that this was the cause of the trouble experienced in the boilers referred to by Messrs. Spear and Carson.

Mr. Spear noted that in the boilers of the "Tasso" and "Sea Horse" the furnaces were flanged to the tube plate with a small radius, and that the tubes were close to the furnace tops. Under these conditions it was only natural that it should be impossible to keep the back ends in order. Mr. Carson's method of minimising the leakage was most instructive. He took care to open only one fire door at a time when firing, and when standing by he put on the ashpit dampers and closed the funnel damper, instead of opening the fire doors; that is to say, he tried to keep the furnace as near one temperature as possible.

Another undoubted cause of leakage at the tube ends was due to overheating of the tube plates, owing to the water being kept away from the plate either by a film of grease or, more often, by excessive evaporation from the surfaces. A combustion chamber with a fire-brick back would act injuriously in two ways. In the first place, any cold air coming into the combustion chamber from the furnace when firing would impinge upon the fire-brick, and would be thus raised to a higher temperature than would be the case with an ordinary wet back combustion chamber. The consequence of this would be that the difference of contraction between the furnace and the tubes would be greater in the case of the fire-brick back—the contraction of the furnace being, of course, the same in both cases. In the second place, a fire-brick back would probably cause an increased evaporation from the tube plate. The steam generated by, say, the first 2 inches of tube surface would also have a large effect in keeping away the water from the tube plate. Now, it is a well-known fact that boilers of the locomotive type can be forced to a greater

extent than boilers of the return tube type, although the tube plate of the locomotive boiler is exposed to direct radiation from the fire. The natural conclusion is, that leakage at the back end of the furnace and at the tube ends is due at first to the contraction of the furnace when the fire doors are opened, the tube plate of a locomotive boiler being attached to the fire-box sides only is, of course, not exposed to a similar stress.

When the leakage is once started it will be aggravated by excessive evaporation from the tube plates, and if the fires are sufficiently forced the evaporation may be increased to such an extent that the water will be kept away from the plates, the result being that they will become overheated and buckle, leakage at the tube ends taking place, not perhaps, because the plates are overheated, but because they buckle.

Returning to the boiler proposed in the paper, it will be seen at once that it possesses a great advantage over the ordinary return tube boiler, viz., that the tube plates are not attached to any part of the structure exposed to alternate expansion and contraction. The tubes themselves will be kept at a practically uniform temperature, as the air entering the furnace, when firing, will be thoroughly heated before it goes through the tubes, so that leakage from this cause will be practically impossible.

Mr. Patterson thought that the present type of boiler could by degrees be worked up for a higher pressure. If so, some means must be taken to relieve the tube plate of the strains caused by the furnace. With the higher pressure the furnaces must of necessity be thicker, and consequently stiffer longitudinally, thus throwing an increased strain on the tube plate.

The other point to be considered in the design of boiler proposed in the paper is, whether the evaporation from the tube plates will be excessive and likely to cause trouble.

To make the comparison between the two types it will be assumed that, in the present type boiler, the amount of "direct" heating surface is equal to half the heating surface of the furnace, the heating surface of the flame box, sides, and top, heating surface of the back tube plate, and of the first 2 inches of the tubes. This surface in a boiler 13 feet 6 inches diameter × 16 feet long = 368 square feet about. The "direct" heating surface in the proposed boiler is equal to that of the back tube plate, and the first 2 inches of the tubes=160 square feet about. On an actual trial of a present type boiler of the above dimensions, under ordinary natural

draught conditions, the amount of coal burnt was about 2,270 lbs. per hour. Hence coal per square foot of "direct" heating surface $= \frac{2,270}{368} = 6{\cdot}1$ lbs. The coal to be burnt per hour in the proposed boiler would probably not exceed 1,000 lbs. per hour under ordinary economical conditions. Hence coal per square foot of "direct" heating surface $= \frac{1,000}{160} = 6{\cdot}2$ lbs.

This calculation assumes that the flame box, sides, and top of the present type boiler evaporate as much per square foot of surface as the tube plates, which, as pointed out by Mr. Marshall, is not the case; so that the above comparison is scarcely fair to the proposed boiler.

To sum up, Mr. Patterson and several of the other speakers maintained that the proposed boiler would fail from leakage at the tube plates. They assumed that leakage at the tube plates in the present type boiler was caused solely by excessive evaporation, whereas it appears quite plain that leakage is due to two causes:—First and foremost, to the alternate expansion and contraction of the furnace; and secondly, to buckling of the tube plate caused by overheating, due to excessive evaporation.

The proposed boiler is entirely free from the first defect; and, as pointed out, the evaporation from the tube plate under ordinary conditions would not be such as to cause the slightest trouble.

If for special reasons it were required to burn an abnormal amount of coal per square foot of heating surface, and if it were anticipated that an excessive evaporation would take place from the tube plates, the remedy is obvious—viz., to increase the diameter of the boiler, and decrease the length, thus obtaining the requisite amount of tube plate heating surface.

Mr. Kilvington asked why, when discussing the relative efficiency of steam of 100 lbs. pressure and steam of 150 lbs. pressure, the terminal pressures were taken as 8 lbs. and 6 lbs. respectively? These pressures were taken because they are the average terminal pressures of compound and triple expansion engines, and with quadruple engines it will probably be advisable to run down to 5 lbs. The relative economy could also have been calculated by means of the ratios of expansion, but the terminal pressure method is more convenient. Of course it might be argued that the terminal pressure might be determined by other causes than due to the performance of work, such as the drop between cylinders, but a comparison of the expanded diagrams of compound and triple expansion engines will show that the loss from these causes is about the same in each case.

Mr. Kilvington also asked why the ordinary thermo-dynamic formula was not used—by which it will be inferred that he means Carnot's formula—

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1}.$$

This formula was not used, because it is not true when applied to steam as used in an ordinary steam engine. As Mr. Kilvington pointed out, the increase of efficiency given by Carnot's formula is only about one-half of that as calculated by the method used in the paper.

Mr. Weighton spoke of the higher temperature to be dealt with in the case of steam of 250 lbs. pressure. When going from the compound to the triple the increase of temperature was about 30 degs. Fah. If the pressure was raised to 250 lbs., the increase of temperature would be about 35 degs. Fah. With the recent experience gained in the case of the triple it ought to be easier to rise from 150 to 250 than it was to rise from 100 to 150. He (Mr. Cummins) was very glad Mr. Weighton had supported his contention for equal initial loads. If engine builders were to send away their engines with equal initial loads superintendent engineers would soon change their ideas.

Mr. Weighton also called attention to the tube surface of the proposed boiler and, like Mr. Fothergill, assumed that it would be inefficient, which, of course, would not be the case. The tube surface of an ordinary type boiler evaporates less water per square foot of its surface, not because it is tube surface, but because the other surfaces have taken the lion's share of the heat.

Mr. Weighton then referred to Mr. D. K. Clark's experiments on a boiler with tubes 66 inches long, in which the first 6 inches of the tubes evaporated more than the whole of the remaining 60 inches, and remarked that, in the model boilers he referred to, there was scarcely any evaporation from the tubes except near the tube plate. He did not say so, but he conveyed the impression that the greater part of the above surface in these cases could have been dispensed with.

Now, in the first place, although the last portion of the heating surface does not do so much work as that nearer the fire, this is no argument for abolishing it. The low pressure cylinder of a triple expansion engine only does about one-third of the total work, but this is no reason for doing away with it. In the second place, the heating surfaces of a boiler are much more efficient when clean. When a boiler is first started with everything clean, both on the water side and the fire side, the greatest duty is done by the surfaces nearest the fire. After a

time these surfaces become dirty, and therefore, less efficient and then another portion of the surface comes into action. It is thus that the amount of water evaporated by a boiler does not vary much under different conditions of cleanliness, and it is this consideration which should mainly determine the amount of heating surface required.

Mr. Marshall referred to the boilers of the "Royal Dane." As pointed out when replying to Mr. Patterson, the trouble was probably due to the furnaces being attached to the tube plate, combined with fire-brick flame box backs.

In reply to Mr. Arnison one point might be touched on. This is the question of tandem cylinders. Owing to the increased facilities for quick loading and discharging of cargoes, the time spent in port is very much less now than formerly, and for this reason every facility should be given for overhauling and examination of the engines. If only for this reason tandem cylinders should not be adopted unless no other arrangement is possible.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

FIFTH GENERAL MEETING OF THE SESSION, HELD IN THE NEW HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON MONDAY EVENING, FEBRUARY 2ND, 1891.

H. MACOLL, ESQ., VICE-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held at West Hartlepool, on January 10th, which were approved by the members present and signed by the Vice-President.

The ballot for new members having been taken, the Vice-President appointed Mr. George Brown and Mr. J. F. Walliker to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Barrow, A. R., Engineer, Indian Railways, Sukkur.

Edwards, Guy Williamson, Engineer, Messrs. Palmer's Shipbuilding Company; Byethorn, Corbridge.

Ellis, Robert Ellwood, Shipyard Manager, Messrs. John Scott & Co., Abden Shipyard, Kinghorn, N.B.; Park Place, Kinghorn.

Quicke, Herbert John, Engineer, Messrs. Blaydon Iron Works, Blaydon-on-Tyne; Summerhill House, Blaydon-on-Tyne.

The discussion on Mr. Hök's paper, on "The Unsinkability of Cargo-Carrying Vessels," was resumed.—Mr. Hök replied.

The discussion on Mr. M. Sandison's paper, on "Main Steam Pipes," was resumed.—Mr. Sandison replied.

A paper, written by Mr. A. Blechynden, on "The Influence of the Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance," was read by Mr. B. G. Nichol.

ADJOURNED DISCUSSION ON "THE UNSINKABILITY OF CARGO-CARRYING VESSELS."

The VICE-PRESIDENT observed that it was unfortunate so many of their prominent members were unable to be present; but as there was a very full meeting, he hoped they would have a good number of speakers. They would first resume the discussion on Mr. Hök's paper, and he would be very glad to have their views on the subject. Mr. Hök had put in his paper a few questions to which he would like to have replies before he submitted his second paper, which was supplementary to that now before the meeting. Surely there were a few present who had some ideas on the subject of bulkheads and the unsinkability of ships.

Mr. J. GRAVELL (of Bureau Veritas) said that he would like just to make a few remarks in reply to Mr. Phillips's statement regarding a vessel which he said was refused by Lloyd's, in consequence of the bulkheads not being carried up high enough, and accepted by the Bureau Veritas. He (Mr. Gravell) wished to inform them that the vessel referred to by Mr. Phillips had all the bulkheads carried up above the load-line.

MR. HÖK'S REPLY.

Mr. HÖK, in reply, said the paper just discussed was written not only with a view to showing that Lloyd's subdivison was insufficient, but also that in subdividing ships not only length, but draught and type, fineness, sheer, proportions, etc., must be taken into consideration. It also invited criticism on the method of calculation, and, above everything, invited the members of this Institution to consider the conditions for unsinkability laid down. This was done with a view to preparing the way for the paper he was going to read in April, and also in order to make the results of his investigation with regard to subdivision, that would then be laid before them, more acceptable. This being the purpose of the paper, he would not trouble them with his reply to those gentlemen that considered proper subdivision a nuisance, as such a reply on his part would necessarily cover some of the ground he was going to traverse in his second paper. He begged them to wait until then, and expressed the hope that they would not take it as discourtesy on his part not to reply to them that night. He would therefore limit himself to replying to those speakers who had criticised the method of investigation and the conditions for unsinkability laid down.

Mr. Johnson asked him the question, what error was involved, in case of ships with long holds, in assuming the moment of inertia of the lost portion of the water-line equal to nothing? He had not worked it out for actual ships, but suppose they took a rectangular box and cut off a compartment in size equal to one-third of the length from either end (and he did not think they would find holds much longer than one-third of the total length of ship, nor commencing at the extreme end, which made the case, of course, worse), then he found the error to be 2·5 per cent. of the additional draught. He thought he might with safety put it to less than 2 per cent. for a ship, but assuming 2 per cent. it meant, with an additional draught forward say of 13 feet, an error of 3 inches. Say the ship's load draught was 25 feet, and the error in draught was 3 inches in 38 feet, which was undoubtedly small. These figures would then show that the assumption of putting the moment of inertia of the lost portion of the water-line equal to nothing was justified. If he took the hold of ordinary length, say one-fifth of the length of ship, the error was unappreciable, as it would not amount to one-half per cent. of the additional draught.

In connection with this he might as well point out now that the mistake mentioned by Mr. Thomson was fortunately no mistake. Mr. Thomson said, "in the Appendix he had found one small mistake. In stating, immediately after equation (1), that $v_1 = v + a\,(d_1 - d)$, Mr. Hök had assumed that the mean draught d_1 of the ship represented the depth of water in the hold. Now, if the hold in question was near the end of the ship the depth of water might be very much greater than the mean draught of the ship. While pointing out the mistake he would say that perhaps it would turn out to be of little importance practically." He thanked Mr. Thomson for putting it so mildly, because he (Mr. Thomson) knew as well as he (Mr. Hök) did that if the mistake had been a real one it would have been a very serious one indeed, and have affected the results considerably. Therefore he would try to explain as clearly as possible why it was no mistake. He knew that Mr. Thomson was experienced in this kind of work, but also that he had done it in a different way. He started from an arbitrary inclined water-line, and then found out by calculation whether the centre of buoyancy was vertically below the centre of gravity. In that case he was right in using the actual volume of water let in to the ship, but not so if he started from the ship being on even keel and found the travel of the level centre of buoyancy by the metacentric method. Then he must consider the volume of the water up to the level draught d_1 and no further, because on that

volume depended the position of the level centre of buoyancy after the ship was immersed to the level draught d_1, on which distance from the centre of gravity, on the other hand, the trim afterwards depended. Mr. Thomson also asked him if he had made actual calculations and compared them with the results from these formulæ. Well, he had, and found no difference. It must be stated, however, that he used the metacentric method in these calculations and had never bothered with inclined water-lines. So, therefore, he thought he would ultimately be found right when he said that whenever the metacentric method of trimming ships was considered correct enough these formulæ were too. Besides, to use a short formula, although slightly approximate, was always preferable to a long elaborate calculation. Finally, in calculating the chances of a ship foundering or keeping afloat in a collison he did not think anyone should be particular to an inch or two, and for that reason the metacentric method was more than accurate for all practical purposes.

Mr. McGlashan spoke about the value of double bottoms. Of course, he thought of ships touching rocks and getting off again. In such a case the value of the double bottom was undoubted. On the other hand, in case of two ships colliding, the double bottom was of little value, as it would in nine cases out of ten be damaged and lose its buoyancy.

With regard to Mr. T. Phillips, the first part of his contribution, or, rather, everything that had any direct bearing on the paper was very amusing. He said: "Several of the assumptions might be avoided altogether, and something of a more definite character stated. For instance, if he understood the paper, it seemed to him slightly out of order to assume that the hold should be perfectly full of water, completely filling it up to the beams, while the ship would be floating with a considerable part of the deck out of water," It is needless to say he had not assumed anything of the kind. No; with regard to the height of water, he had considered nature's own case, which was that the water surface remained stationary, and the ship after being struck sank to certain draughts which depended on the amount and position of the buoyancy that was re-distributed. Then, in consequence of this seemingly great blunder, which he did not commit, Mr. Phillips compared his investigation with those of Messrs. Barnes and Dunn. In that comparison Mr. Phillips again favoured them with some inaccurate statements. For those interested in the subject and who would prefer to judge for themselves, he might mention that Mr. Barnes's paper was to be found in the Transactions of the Institution of Naval Architects

for 1867, and that of Mr. Dunn in the Transactions of the same Institution for 1883. Mr. Barnes did not treat the longitudinal stability or the change of trim at all, but contented himself with showing the effect on the transverse stability or on the heeling over sideways of a rectangular box, when compartments of different size and position were filled with water. So, consequently, there was no need for any comparison here at all, as the two papers did not treat of the same subject. Mr. Dunn's paper, on the other hand, discussed the advisability of fitting more bulkheads in ships, and he proved the necessity for increasing their number by an experimental method. He made two models of an existing ship. One he subdivided according to the Admiralty requirements, the other according to the existing fashion in ordinary merchant steamers. Then he let in water in the different holds, and showed by that means that the ship subdivided according to the Admiralty requirements would, under many conditions, keep afloat, when the ordinary ship would founder.

With regard to the communication from Mr. Piaud, he thought the Institution as a body should feel extremely obliged to that distinguished Frenchman for the great interest he took in the Institution, and for the valuable matter he communicated from time to time. And he, for one, was sure that it was far from Mr. Piaud's intentions to disparage Lloyd's as Mr. Phillips suggested. He thought, instead, that he (Mr. Piaud) by his communication, wanted to show that, on account of the rules for subdivision being different in the society which he represented, it would be unfair to assume that the conclusions he (Mr. Hök) had come to with regard to ships subdivided according to Lloyd's rules would equally apply to ships classed in Veritas.

With reference to the questions he had asked towards the end of the paper, he was glad he had at least got one reply, and that was furnished by Mr. Thomson. The other speakers had wholly ignored them. He would take their silence as a sign that they agreed with Mr. Thomson and himself that the conditions for unsinkability were not out of the way, and that the formulæ were correct enough for the purpose. With regard to the number of compartments that should be bilged simultaneously, he did not agree with them that two compartments should be opened out to the sea in the case of cargo vessels, but he begged leave to give his reasons for that in his next paper.

In conclusion, he begged to thank them for the kind way in which they had received his paper, and especially to thank Mr. Macoll, not only for his valuable contribution to the discussion, but also for the

interest he had shown in connection with this matter in his practical suggestion of having the paper discussed at Hartlepool, so as to enable him to get some valuable information before he commenced the preparation of his second paper.

The VICE-PRESIDENT thought, if they had not given Mr. Hök very great assistance in his investigations so far, they, nevertheless, appreciated his labours. He hoped the next time the subject was brought before them members would be prepared to ventilate their opinions more fully and freely. In the meantime he was sure this meeting would accord to Mr. Hök a very hearty vote of thanks for his labours in the cause of scientific investigation and increased safety of ships at sea.

The proposal was carried by acclamation.

ADJOURNED DISCUSSION ON "MAIN STEAM PIPES."

Mr. J. F. WALLIKER said, in the first place, that in spite of all that had been adduced to the contrary he was still a strong advocate for the continued use of copper pipes. Mr. Sandison, in his paper, had criticised them and showed all the dangers to which they were liable, but, in his view, it should have been shown a great deal more clearly where the danger from them really arose. No doubt most of them were aware of the paper read, some couple of years ago, before a kindred institution, on the "Elbe" explosion. The drawings then produced showed that the liability to burst invariably took place somewhere near the brazing of the flange, and this was very properly attributed to defective workmanship. The process was this: first, the heat was applied for loading the joint, then the flanges were brazed on, and the explosion almost invariably happened through overheating in the manufacture at this point. With copper pipes, of course, they were entirely in the hands of the coppersmith, and that was a very great drawback, but he believed, with careful supervision, even that objection could be almost overcome. They had had last year, on the Tyne, about 100 ships turned out, and each of these would have, on an average, three main steam pipes, and they could say with confidence that they had never had a complaint as to the workmanship and material. As a rule, the pipes that had gone away gave every satisfaction, and if they took the number in use they would find the percentage that had failed very small indeed. Mr. Sandison had turned their attention to steel pipes as having done so well and given no trouble whatever. The pipes spoken of in the paper, it should be remembered, were made under the strictest supervision and everything was done to them that experience and forethought could suggest; not only were they screwed, but the flanges were brazed on as well, and they were designed with a factor of safety of 40, so that their immunity from accident was what they might expect from the facts of the case. He (Mr. Walliker) directed attention to a sketch of a main steam pipe which, he said, came off the S.S. "Mary Thomas," working under ordinary conditions in a triple expansion engine of 160 lbs. pressure. (See Plate XIX.) This vessel ran ashore while under full pressure, and the boilers were lifted up something like a foot. This pipe came in contact with a beam and was deflected in the manner indicated. The

vessel steamed home under the full pressure, and he thought that that fact alone should give them a very great deal of confidence in the pipes as at present made. There was one other matter that might be added, and that was with regard to the need or otherwise of annealing pipes after long continued use. His own experience was that this was quite unnecessary with the old main steam pipes, which were comparatively easily bent after years of work, and he could see no necessity, until it was absolutely demonstrated, of any further trouble with those working at the higher pressures, which, after all, meant only about 40 degs. rise in temperature, to balance which there was a great increase in thickness of the material used, and care in testing after manufacture.

Mr. ALEX. TAYLOR did not know that he had anything to say upon this iron steam pipe question except that he still firmly believed in iron steam pipes, and although he had not pressed the question for many years now upon builders, it was because he had so great a difficulty in getting them to take the question up and give iron pipes a trial. So far as practical utility was concerned, he thought the samples Mr. Sandison showed the other night were quite enough to prove that iron pipes were reliable and that they did not deteriorate much. He thought the Institution ought to be extremely obliged to Sir William Armstrong & Co. for taking advantage of Messrs. Fisher, Renwick, & Co.'s permission to take the old steam pipe out after running eight and a half years and do anything they liked with it, provided they put another in its place. They would quite understand that the pipe was not taken out of the ship because it was defective; it had never given the slightest trouble. It was taken out solely for the purpose of experiment.

The VICE-PRESIDENT thought they had the case for the iron pipe put very clearly and strongly, and it would be very difficult to say anything against it. It was a pity that those with different views did not rise to express them. He had now to call upon Mr. Sandison to reply.

MR. SANDISON'S REPLY.

Mr. SANDISON said he did not propose to take up much of their time in replying to the discussion on his paper. He must say he was at first somewhat surprised on examining the sample of electro-deposited copper introduced in the course of the discussion at the last meeting in Newcastle. It appeared to him to be a flagrant case of intermittent action during the depositing process, and when they considered that a week would be occupied in depositing a layer of copper $\frac{1}{8}$ inch thick, it was

obvious that this required to be carefully guarded against. Any temporary stoppage of the depositing dynamo while the mandril was revolving would infallibly produce a lamination. He had not thought it worth while to bring down again the sample of wrought iron steam pipe which he exhibited at last meeting; if any member who had not examined it cared to do so, he should be glad to give him an opportunity. With reference to Mr. Walliker's strong advocacy of copper pipes as at present made, he thought that the circular embodied in the paper served to show that his (Mr. Walliker's) colleagues in Lloyd's Registry still had this subject under consideration. He (Mr. Sandison) was not in a position to advocate one material in preference to another. What he looked for was the safest material; and when solid drawn pipes were found to be anything but satisfactory, it was necessary to look elsewhere for a substitute. He thought that a mild steel pipe would have stood the same amount of deflection and distortion that Mr. Walliker had described in the case of the S.S. "Mary Thomas." He had to thank them for the reception they had given to his paper. He could only claim credit for bringing the subject, which he thought was in a somewhat unsettled state, before the Institution. On the surface it did not appear to be a matter that admitted of much discussion, but in view of current events he thought it deserved a great deal more attention than was usually bestowed upon it.

The VICE-PRESIDENT said there could be very little doubt that copper pipes, at the pressures they were now keeping in marine boilers, was a very important item indeed, and pressures were not likely to decrease. The manufacture and application of piping for the conveyance of high pressure steam was a very important consideration. This Institution was indebted to Mr. Sandison for bringing the matter before them. It was rather a vexed question at the present, and not at all a comfortable matter for anyone in the stokehole or engine room to consider the fearful amount of risk there was resting upon one individual in finishing up one of those pipes. It was necessary that the greatest amount of care should be taken, and in most cases was taken; still, the accidents which had occurred went to show that all reasonable precautions should be adopted to secure safety, not only in the manufacture but also in the fitting of the pipes, so as to give sufficient room for expansion and ample support to the pipes, and thus avoid undue strains coming on the flanges and bends. It was also imperative that the main boilers should be designed and worked so as to avoid priming as much

as possible; he believed the presence of water in the pipes had more to do with the failure of steam pipes than was generally understood, and it was highly desirous to have pipes the strength and endurance of such as had been described in everyday practice. He moved that they accord Mr. Sandison a hearty vote of thanks for his paper, and hoped it would not be his last upon kindred subjects.

The vote of thanks was cordially adopted.

SCREW PROPELLER: THE INFLUENCE OF THE RELATIVE DIMENSIONS AND PROPORTIONS OF THE SCREW PROPELLER ON THE VESSEL'S PERFORMANCE.

By A. BLECHYNDEN.

[Read before the Institution in Newcastle-on-Tyne, on February 2nd, 1891.]

When in 1887 the writer presented a paper on the screw propeller to this Institution a desire was expressed that it would be well to show the application of the facts then adduced to the designing of screws for the propulsion of vessels. Since that date, want of time has prevented the writer presenting another contribution upon the subject, though the experimental data have been made the basis for the construction of diagrams for service in the designing of screw propellers which have been continuously used for that purpose since. Besides this, a description of the method was written, and has passed through the hands of some members; but, though at first intended for publication, it was withheld because the writer felt that some points were left unnoticed which could not, with wisdom, be omitted in a discussion of the subject.

The present paper while primarily intended to be a discussion and comparison of the trial data of certain vessels, and of the relation of the dimensions of the screws to the sizes of the vessels they were used to propel, will also briefly refer to a method of calculating the power which can be developed upon a screw of given dimensions, based on the model experiments with which the former paper chiefly dealt, and will show, by a series of examples, the relation of the powers so calculated to those obtained on trial.

As model experiments form the groundwork of the method of comparison to be used, and of the quantitative factors on which many of the calculations are based, it were well at the outset to state what, in the writer's opinion, the value of such data is.

Any screw, no matter what its dimensions may be, can be regarded as a model, and the data obtained from its trial may serve to give the

quantitative factor by means of which the results obtainable from a similar screw, working under similar conditions, may be calculated—granted that the law of variation, with change of dimensions, has been determined. There is no absolute restriction to size in the idea of a model.

Convenience and economy, however, rule that experimental models should be small; but smallness of size of the model is no sound argument against the value of the results obtained from it, provided that the instruments by means of which the measurements are made are such that their readings can be taken with the same degree of accuracy as the measurements of speed and power can be made in the full-sized machine. In the case of model screws of over 12 inches diameter this is certainly possible. Experiments on small models tried in undisturbed water also offer the very great advantage that, by their means the effects of change of form or proportion can rapidly be studied, as they are freed from the concrete mass of variables involved in the problem of a screw applied to a ship, and thus general conclusions can much more rapidly and certainly be arrived at. In passing, however, from one extreme of dimension to another it is necessary to give due consideration to the possibility of the results varying otherwise than in accordance with some preconceived hypothesis, and to reckon on the possibility of similar allowances as have to be made in passing from the resistance of the model of a ship to that of the ship itself being necessary.

In this connection it is safe to say that without models tried in still water it would have been impossible to have determined, with anything like approximate accuracy, the efficiencies of, and the relative powers which can be developed on screws of different pitch and surface ratios.

As to the conditions of model trials, it appears a matter of indifference whether the screw moves through the water or the water moves to the screw. If the pitch and revolutions are the same in two cases, and in the one the water is stationary, and the screw moves through it at the same speed as the water moves to the screw in the other, the screw being stationary, the results must be dynamically the same. Our ideas of motion are altogether relative. The problem of a screw's resistance is not one involving the measurement of motion relatively to the observer, but of the velocity of the screw and the water towards each other. Relatively to the observer, the one may move and the other be stationary,

. may move; all other things being equal, so long as the sum of

ties towards each other remains the same the thrust will also be.

the same, and either of the two conditions just mentioned, or a combination of both, is precisely such as a screw fitted to a vessel might work under, barring, of course, the fact that the wake of the vessel has slightly varying speeds at different parts. A screw may propel a vessel through still water, it may just serve to maintain it stationary relatively to the earth against a head current, or it may propel it at a slower speed than in still water against a head current. The second is precisely similar to a screw being tested in a tank with the water in motion.

There is, however, a good deal of difference between the conditions under which a screw works propelling a ship and those under which it works in undisturbed water, inasmuch as in the former case it works in a mass of water having different speeds at different portions of the column flowing towards it. But the difference in effect is not so great as many seem to think, and, as will be shown, not so great but that if the mean speed of the wake be taken in estimating the slip, then the results of experiments made upon models in a free stream may serve to supply data by means of which the power developed on screws fitted to propel vessels may be predicted with sufficient accuracy for all practical purposes.

In the application of the model data to the calculation of expected results from actual propellers the first step was the preparation of a diagram (Fig. 1, Plate XX.) giving the values of K for various slip and pitch ratios in the old formula,

$$\text{I.H.P.} = \frac{D^2 \times A^3}{K},$$

D being the diameter of the screw in feet,

A the speed of the screw's advance in knots per hour, *i.e.*, revolution into pitch, and

K a divisor depending on the pitch, surface and slip ratios.

This diagram, being immediately calculated from the results obtained from the series of models having blades of the same form but with different pitch ratios and described in the writer's former paper, is, of course, only strictly applicable to screws of this particular form and surface ratio or those of another form with equivalent surface ratio; but as the power is, roughly speaking, approximately proportionate to the square root of the surface ratio for small changes in a similarly distributed surface, suitable approximate modifications may be made for other ratios, so long as the pitch ratio is not above 1·5 nor beneath 1·0. Fig. 2, Plate XX., is an outline of the blade of the experimental models developed on a flat surface.

The diagram is constructed as for the power developed in the cylinders on the assumption that the relation of the power available for working the screw and propelling the ship is ·83 of that indicated. The basis on which this has been determined is appended. Doubtless this is, in many cases, considerably too high, but there seems no reason why a well-constructed triple expansion engine should give less than this when working at full *trial* power. If the circulating pump is centrifugal and the feed and air pumps are independent so as to be regulated to do just the exact work, there is no reason why the modulus of the whole machinery should not be somewhat higher.

In order that the effects of quantity and distribution of surface might be determined with greater accuracy, the diagrams Fig. 3, Plate XXI., and Fig. 4, Plate XXII., were prepared.

That numbered 3 was constructed from the data obtained from experiments made with a set of model screws, the figures of whose blades were parallelograms. These were successively tried with portions of their blades removed, or, in some experiments, what was equivalent to this, and by this means the thrust values of the surface ratios in the various concentric rings from the circumference inwards were determined. The net result of the whole process was that it appeared sufficient for all practical purposes to measure the widths of the blades on four concentric circles whose diameters were ·95 D, ·85 D, ·75 D, and ·6 D, to divide the sum of the widths of the blades on each circle by the outer diameter D, and to use the result as a comparative surface ratio for that portion of the disc. The moduli for these surface ratios relatively to a standard blade were plotted down, and the curve in Fig. 3, Plate XXI., was the result. It is exactly the same curve as that for surface ratios shown in the former paper. The three outer circles have one common scale and the inner portion another. The moduli being found for the four divisions of the disc, they are added together, and the sum is the relation of the work done on a screw of 1·25 pitch ratio whose blade is of the form measured to that done on one whose blade is similar to Fig. 2, Plate XX., and whose pitch ratio is 1·25, the screws being equal in diameter and working with the same advance and slip. To describe the whole process by which the result was arrived at might be more satisfactory and perhaps interesting, but it would be tedious, and consequently it may suffice to give an example to illustrate how the diagram may be used, and two others to show its agreement with actual experimental result.

The blade shown in Fig. 5, Plate XXII., will be taken, and for a four-bladed screw of 10 units diameter.

Radius.	Width of Blade.	Comparative surface = width of Blade × number of Blades ÷ outside diameter.	Modulus compared with Blade, Fig. 2.
$\frac{9{\cdot}5}{2}$	·892	·3568	·150
$\frac{8{\cdot}5}{2}$	1·242	·4968	·190
$\frac{7{\cdot}5}{2}$	1·540	·6160	·217
$\frac{6}{2}$	1·970	·7880	·400
			·957
Relative value from experiment			·964

In the case of a four-bladed screw whose form was that of a slice of a true screw and whose surface ratio was ·38, the modulus calculated by the assistance of the diagram was 1·1592 and the experimental result gave 1·1600.

For a two-bladed screw with rectangular blades, but with a surface ratio of ·19, the diagram gave the modulus of ·704 and experiment ·71.

These show sufficiently close agreement to give confidence in the use of the diagram.

As the results just given are for screws having pitch ratios of 1·25 only, and it is, or ought to be, well known that the relative values of different surface ratios are not the same when the pitch ratio is changed, it becomes necessary to have some means whereby the necessary allowance may be made for change of the latter.

The Diagram Fig. 4, Plate XXII., supplies this want.

The object of the diagram is to supply multipliers for K in Diagram 1 for other types of blades than the standard blade and ratio for which it was constructed. The standard blade of Diagram 1 is, therefore, unity for all pitch ratios in Diagram 4, and the nominal values of the various curves, named "Values of C" in the diagram, are the relative thrusts of screws with blades of various sizes and forms as found from Diagram 3 for a pitch ratio of 1·25. The values for other pitch ratios are found by means of the general scale. This diagram is not absolutely correct, but it is sufficiently accurate for practical purposes, and may serve until further and more varied experiments are made.

It is most important to put any proposed method of calculating the powers developed on screws to the test of comparison with trial results, when, unless there is a rational agreement shown between the two, the proposed method may be abandoned as valueless or must undergo modification. A comparison will now, therefore, be made with the calculated powers and those developed on trials of which the data are sufficiently extended and accurate to warrant a comparison.

The results are shown on Table IV. (page 185), and it is needless to comment on the last two columns of figures, except that perhaps the variations of the one from the other are much smaller than would have been expected.

The examples given are only of screws of cast iron, steel, or gun metal of heavy section. If a similar comparison were attempted in the case of screws whose blades were made of the stronger bronzes, when it is customary to make the sections much lighter, a difficulty would be met with, due to the bending of the blades under the pressure to which they are subjected, the effect of which is to increase the working pitch. This is so obvious as to lead one to expect such an increase of working pitch, but the extent of the increase was only recently for the first time brought before the writer's observation in the case of an Atlantic liner belonging to a well-known company. A screw with strong steel blades was originally fitted, with the result that $64\frac{1}{2}$ revolutions gave the vessel a speed of 14 knots. The steel blades were afterwards removed and replaced by a set made of manganese bronze moulded from the original pattern blade but made thinner. These were fixed on the boss at one foot finer pitch than that at which the steel blades were set, with the result that at the speed of $14\frac{1}{4}$ knots the revolutions were $62\frac{1}{2}$, or two less than were required by the coarser pitched original propeller for $\frac{1}{4}$ knot less speed. This seems to indicate that the working pitch of the bronze blades was $\frac{14{\cdot}25 \times 64{\cdot}5}{14 \times 62{\cdot}5} = 1{\cdot}05$ of the original pitch, and, as they were set at 23 feet against 24 feet in the original, their pitch must have increased to $24 \times 1{\cdot}05 = 25{\cdot}2$ feet, or about 9·5 per cent. increase over the 23 feet at which they were set. This fact is further borne out in the cases of two other vessels of which the following figures give the results, from one only. In this case steel blades were replaced, as in the case just cited, by manganese bronze blades of precisely the same form but of lighter section, and they were set to the same pitch as the first blades.

TABLE IV.

Vessel.	Screw Propeller.			Trial.					From Diagram for Standard Blade and Total Slip.	Multiplier for Type of Blade.	Modulus of Engine.	K^2.	Calculated H.P.	Actual H.P.	Remarks.
	Diam.	Pitch.	Ratio Pitch.	Revolutions of Screw.	Speed of Ship.	Speed of Screw. A.	Wake, Fraction of Ship's Speed.	Total Slip as Fraction of A.	K.	B.	C.				
	Feet.	Feet.			Knots.	Knots.									
A	24·0	33·416	1·392	62·54	18·235	20·61	·252	·338	427	1·00	·83	427	11,860	11,890	Tandem compd., 3 cranks; circulating pumps separate.
B	16·5	22·0	1·331	77·00	15·296	16·71	·196	·256	510	1·00	·80	529	2,400	2,436	Compd.; all pumps worked by engine.
C	14·0	18·25	1·301	125·0	18·776	22·50	about ·055	·211	612	1·02	·83	625	3,575	3,591	Compd.; pumps separate, but power added to I.H.P.
D & E	16·0	22·0	1·374	74·5	15·100	16·20	·196	·250	555	·88	·80	470	2,300	2,306	Compd.; all pumps worked by engine.
F	18·16	20·5	1·13	76·96	14·288	15·57	·276	·335	333	1·00	·83	330	3,900	3,948	Compd., air, feed and bilge pumps worked by engine.
G	15·0	16·33	1·09	93·48	13·133	15·08	·256	·357	298	1·19	·83	355	2,178	2,116	Do. do. do,
H	15·0	16·33	1·09	94·47	13·366	15·21	·264	·363	295	1·19	·83	351	2,260	2,191	Do. do. do.
J	16·5	15·95	·969	93·67	12·93	14·75	·264	·354	266	1·281	·83	342	2,555	2,447	Do. do. do.

K^2 is found by $\frac{K \times B \times C}{\cdot 83}$.

Mean results on voyages were—

	Speed.	Revolutions.
Steel	18·45	66·02
Bronze	18·39	61·96

Equivalent to 6·1 per cent. apparent increase of pitch.

It appears from the calculations, the results of which are given in Table IV., that the data of model experiments are applicable to the estimation of the power expended in working screws when applied to the propulsion of ships, the exact data of the latter being known; and it might be supposed that an efficiency curve, or a series of them, in conjunction with Diagram 1 might serve to determine the propeller of maximum efficiency for any particular case. But at this point the great difficulties begin, as an analysis of trial data very soon shows that a screw designed in the light of model trials to work with the slip corresponding to maximum efficiency of the screw *per se* may not be anything approaching to the screw *propeller* of maximum efficiency, and that, as a matter of fact, in the larger number of cases the screw's efficiency curve is, for this purpose, of no use whatever. Facts go to show that a screw works at maximum efficiency when its slip is about 20 per cent. In the case of *full* cargo ships, the propeller as usually proportioned works with from 30 to 35 per cent. of slip, and sometimes even more; and the curious but quite reasonable fact can be shown that if an attempt be made, by means of a larger screw or an equivalent modification, to reduce the slip to a more efficient ratio, judged in the light of the model efficiency curve, the result would generally be not decreased slip but approximately the same slip with an increased resistance of the whole combination of the ship and screw, and a correspondingly increased power to overcome it. In fact, the ratio of the dimensions of the screw to those of the vessel it propels appears a most important element in determining the power requisite for the propulsion of the whole. In fine vessels with single or twin screws efficiency of propulsion and of the screw go closely hand in hand, but in the case of full vessels they are widely parted. This fact is best illustrated by comparing the trial results of vessels.

To make this comparison absolutely satisfactory it should have been amongst the trial results of a series of vessels of the same size fitted with screws precisely *similar* in form and proportions, but of different diameters, and with engines of the same type, and of equal cylinder capacity, per revolution, per horse power indicated, and tried at exactly the same speeds. The effect of the difference of the screw's size

relatively to the vessel would then have been made clearly apparent, as all other causes of variation would have been eliminated. But, as such a series of examples is unprocurable, what appears the next best thing to it has been taken.

A series has been selected of about the same type whose trials were made at an approximately similar speed, and whose screws were similarly proportioned, the one dimension relatively to the other. The most of the examples had also engines of one type by one maker. Thus, the ideal condition has been somewhat nearly approximated to, and so, generally, most of the causes likely to give rise to variations of the coefficients of performance of the vessels have been got rid of, excepting the relative sizes of the screws to the ships and errors of observation.

After selecting from the examples this series with similar screws, which were nearly 1·25 pitch ratio, and with four blades, similar to Fig. 2, Plate XX., there was still remaining a large number of examples of similar vessels whose screws were otherwise proportioned; but, as by the diagrams which have been given, it is possible to determine the dimensions of a screw of any type which may be taken as the standard, and would require an equal power to work it, with an advance and slip equal to any other differently proportioned, it seemed worth substituting in every case an equivalent screw of 1·25 pitch ratio, and ·38 surface ratio, and making a similar comparison as had been made in the case of those at first selected.

The standard of 1·25 pitch ratio and ·38 surface ratio has been chosen, and is generally referred to as a standard throughout the paper, because it seemed best to have some such standard, and this was, for most reasons, as good as any, and for others, better, because the first set of examples just referred to had screws of this type, and, as it happened, the most of the model experiments which were made to compare the effects of difference of the form and surface ratio were made on models of this pitch ratio, so that it was thus, for convenience sake, doubly acceptable as a standard.

This comparison has been made for a series of full cargo boats, and its results are shown in Tables V. (page 188) and VI. (page 189). Those whose results appear in Table V. are a set whose speeds are about the same relatively to the square root of their lengths, *i.e.*, about ·6 $\sqrt{\text{length}}$. As will be seen the screws of the whole were of a similar type, the pitch ratios being about equal, their surface ratios were also approximately equal, except in two cases where an equivalent screw of the above-named

standard was substituted for comparison. They are arranged in the increasing order of the relation of the augmented surface of the vessel to the screw's disc, and the coefficients of performance in relation to the cubes of the speeds, and the wet and augmented surfaces are given side by side. The values of $\frac{D^2 V^3}{I.H.P.}$ are not given, as being of little value except for exactly similar vessels at similar speeds.

As the great proportion of the vessel's resistance at the slow speeds given consists of skin friction, wetted surface is the most important dimensional element; but, somewhat to level up broad and narrow vessels, the coefficient of augmentation is useful. This is its object in this connection, and involves no assumption of the absolute correctness or otherwise of Rankine's views.

TABLE V.

Reference No.	Length. Feet.	Length. Beam.	Prismatic Coefficient.	Speed. $\frac{\text{Speed.}}{\sqrt{\text{Length.}}}$	Wetted Surface. Disc.	Augmtd. Surface. Disc.	Wet Surface V^3. I.H.P.	Aug. Surface V^3. I.H.P.	Pitch. Diameter.	Remarks.
1	149·25	6·66	·638	·6	35·6 51·3	44·8 64·7	13,200	16,600	1·25 ·895	Single screw, compound.
2	320·	9·02	·725	·620	74·	87·9	16,840	19,900	1·290	Do. do.
3	275·	7·34	·730	·634	68·	89·5	14,700	19,300	1·240	Do. do.
4	270·	7·72	·750	·624	78·2	95·0	16,560	20,100	1·265	Do. do.
5	460·	9·40	·750	·635	81·9	98·0	17,300	20,700	1·29	*Do. triple.
6	260·	7·76	·773	·611	79·1	100·0	16,100	20,600	1·230	Do. compound.
7	270·	7·56	·762	·642	80·5	104·0	16,182	20,920	1·23	Do. do.
8	285·	7·91	·785	·579	86·6	110·6	16,180	20,600	1·19	Do. do.
9	285·	7·7	·752	·590	84·6	107·1	15,700	20,000	1·23	Do. do.
10	300·	8·10	·786	·605	94·1	119·0	16,860	21,250	1·26	Do. do.
11	300·	8·10	·785	·620	94·0	119·0	19,310	23,500	1·26	Do. do.
12	317·	8·49	·762	·619	97·8	119·4	19,500	23,800	1·22	Do. do.
13	338·5	8·5	·710	·628	103·5	125·0	20,000	23,900	1·25	*Do. do.
14	285·	7·5	·800	·609	97·	127·9	17,240	22,750	1·254	Do. do.
15	265·	7·75	·755	·600	104·5	127·5	19,280	24,500	1·25	†Twin screw, triple.
16	285·	7·5	·800	·600	98·	128·9	18,160	24,900	1·254	Single screw, compound.
17	330·	8·92	·764	·6125	103·	130·0	20,600	24,900	1·27	Do. do.
18	285·	8·15	·764	·615	112·	140·0	18,250	22,800	about 1·25	Do. do.
19	338·5	8·5	·720	·628	125·5	152·0	18,750	22,350	1·25	*Do. do.
20	232·	6·12	·800	·600	115·	170·0	11,200	16,600	1·25	‡Twin screw, triple.

† Twin screw. The ratios of wetted and augmented surfaces to the disc area are taken for an equivalent screw of 1·25 pitch and ·38 surface ratio. Its propeller was actually 1·615 pitch ratio and ·52 surface ratio, and the actual ratios of augmented and wet surfaces to the disc were 104 and 82.

‡ This also is a twin screw treated in a similar manner. The actual screw being 1·54 pitch ratio and ·39 surface ratio, and the ratios of augmented and wetted surfaces to disc 132 and 89·4.

All the pitches of the screws given are the measured pitches, which were carefully ascertained after casting in the case of solid screws; in the case of loose blades, they are the set pitches.

The first case on the table is a vessel of a type differing from the rest, and it is fitted with a screw of a much smaller pitch ratio. The ratios of the surfaces are given, both for the true disc area and for that of an equivalent screw of 1·25 pitch ratio; it would not, however, necessarily be a screw of exactly the same efficiency. This vessel is much finer than the others, as indicated by its prismatic coefficient, and its coefficients of performance are consequently greater than they should be for proper comparison in this table.

With the exception of the three cases marked * which are for records at sea between known points, the vessels having clean hulls, the whole are trial trip performances on the measured mile.

If the coefficients of performance are compared with the ratios of the surfaces to the screw's discs it will be seen that, allowing for the slight variations due to errors of observation, etc., the performance improves with decrease of the screw's area up to about the point where the augmented surface is 130 times the area of the disc, and that beyond this ratio the efficiency appears to fall. This is, of course, for vessels of this type and for a speed of about $\cdot 6\sqrt{L}$ knots.

Table III. is additional evidence to the same effect. The vessels are, as already stated, of the same class—east coast cargo boats—but their relative speeds are in some instances a little lower, and vary from $\cdot 55\sqrt{L}$ to $\cdot 63\sqrt{L}$ knots; as, however, the coefficient of performance generally varies but slightly over this particular range of speed for this type of vessel, the difference affects the comparison but slightly. The pitch ratios of the

TABLE VI.

Type of Engine.	No. of Vessels.	$\frac{\text{Augmented Surface.}}{\text{Disc Area of Equivalent Screw.}}$	$\frac{\text{Augmented Surface} \times V^2.}{\text{I.H.P.}}$	Actual Pitch Ratio.
2-Cylinder Compound ...	2	83·0	19,200	1·10
Triple	2	98·7	18,800	·991
2-Cylinder Compound ...	6	103·6	20,530	1·136
3 2-Cylinder Compound 2 Triples	5	115·3	20,922	1·118
2-Cylinder Compound ...	2	127·2	22,325	1·135
1 Triple ... ... 1 2-Cylinder Compound ...	2	134·6	21,600	1·13
Triple	1	140·0	20,800	1·150

screws are also different, being finer—about 1·1 to 1·15 against 1·25 of the previous table. In order, therefore, to make the comparison fair, an equivalent screw of 1·25 pitch ratio has been substituted in all cases and the vessels summed up in groups. The machinery of nearly all is by one maker.

It were well, now, briefly to show the practical bearing of the figures in Table V. (page 188). Compare (or contrast) No. 2 with Nos. 15, 16, and 17. The coefficient of performance of the former referred to augmented surface is 19,900 against a mean of about 24,800 of the latter three; in other words, these vessels required only 80·4 per cent. of the indicated horse-power required by No. 2 per unit of augmented surface and speed, and, as appears evident by the figures on the table, this superior performance is due to Nos. 15, 16, and 17 having been fitted with more suitably proportioned screws, viz., screws having a disc area of 1 square foot to about 128 units of augmented surface against the proportion of 1 to 88 in No. 2.

If, for the sake of argument, it is assumed that No. 2 was tried in exactly the condition and at the speed at which it was intended to trade, a brief calculation will show the advantage to its owner had it been fitted with a propeller proportioned like Nos. 15, 16, and 17. Its speed was 11·1 knots and its indicated horse-power 1,347. It is but a rational conclusion from the evidence that, had its propeller had a disc area of 1 square foot for every 128 units of augmented surface, the power would have been $\frac{19,900}{24,800} \times 1,347 = 1,080$, or 267 less than it actually was. This is an economy of, roundly, 20 per cent.

The improvement in the vessel's working would have been as follows, assuming the engine of the triple expansion high pressure type to bring the example up to date:—

Less coal per day at 1·6 lbs. per I.H.P. per hour ...	4·6	tons.	
Less coal per annum at 224 working days	1,030·	„	
Less coal per voyage of 15 days (run one way)	69·	„	
Less weight of machinery...	62·	„	
Less cost of machinery	£2,300	0	0
Increased capacity for freight, equal to the decreases of weight of machinery and of coal per voyage ...	131·	tons.	
Annual savings and increase of revenue:—			
Saving on coal, at 15s. per ton put on board	£772	10	0
Saving of interest, insurance, depreciation, and repairs on £2,300, at 27·5 per cent.	632	10	0
Increase of freight, 131 tons, at £6	786	0	0
Total gain	£2,191	0	0

It is interesting to note two facts in connection with Table VI. :— Firstly, that generally the performances are somewhat lower than those in the preceding table, and that the pitch ratios are also smaller; secondly, that on the second line in the list there is a fall beneath the others, and that this corresponds with a still lower pitch ratio.

It is doubtless possible that this observed fall in performance may be due to other causes beyond a lower pitch ratio. Its immediate coincidence with it, however, is a sufficient hint to induce the enquiring mind to investigate the matter more closely. Especially does it appear so to the writer, whose experimental data indicated a very rapid fall of efficiency towards these finer pitch ratios.

It might now be interesting to estimate the slips of some of the screws given in Table V.; this is done in Table VII. These have been estimated by calculating the values of K as for Diagram Fig. 1, Plate XX., and then taking the slip ratios corresponding to those values :—

TABLE VII.

No. on Table II.	Screw's Diameter.	Knots Advance.	I.H.P.	$\frac{D^2 \times A^3 \times \cdot 83}{\text{I.H.P. } 80}$	Total Slip.
	Feet.				
2	17·0	12·29	1,347	411	·318
4	15·0	11·44	893	392	·325
10	15·833	12·25	1,325	362	·345
12	16·00	11·00	1,342	374	·325
16	15·58	11·70	1,060	380	·335

From these few examples it would appear as if the slip ratio varied but little over the whole series, although there is about 25 per cent. difference of efficiency in the performances of the cases just selected. The explanation of this appears to lie in the fact that the larger screw, moving a larger mass of water from the stern, considerably decreases the hydraulic pressure upon it, which is equivalent to an equal augmentation of the ship's resistance, and that, within the limits of the experiments, this augmentation is roughly in proportion to the screw's area.

With finer vessels this loss is considerably less felt, so that screws of larger diameter involving a lower slip ratio are more suitable, and ought to be adopted. On fine vessels, say with a prismatic coefficient of about ·6, a slip ratio of ·20 to ·25 may safely be aimed at, when, in all probability, the condition of maximum efficiency will be attained.

Diagram Fig. 6, Plate XXIII., is a comparison of the trial results of a series of vessels at speeds corresponding to $\cdot 75\sqrt{L}$, $\cdot 85\sqrt{L}$, and $1\cdot 05\sqrt{L}$.

The pair of curves for speeds of $\cdot 75\sqrt{L}$, and $\cdot 85\sqrt{L}$, are for a series of fine vessels of various proportions as to length, the variation being between 6·5 and 9·1 beams; but all are vessels with fine lines, the maximum prismatic coefficient being only ·658. Properly speaking, vessels only of precisely the same type should be thus compared in one curve—until, of course, the exact law by which the resistance varies with the form is discovered—but when the vessels are fairly fine, as in this instance, and the speed, relatively to the length, not very high, little error is involved. Besides, in these particular instances the vessels with the finer prismatic coefficients are, relatively to their beams, shorter, so that as a matter of fact the longer ships with the coarser coefficients will not have lines of much greater angular inclination to the line of motion.

All the spots for the higher ratios of augmented surface to the screw's disc (which is again made the basis of comparison) are for single, and the lower for twin screws. From the fair appearances of the curves drawn through the points, about an equal efficiency is indicated for both classes for similar ratios. In the same connection it were well to direct attention to the two cases of twin screws, amongst the cargo boats, in Table V. (page 188), numbered 15 and 20. The performance of No. 15 conforms exactly with those of the vessels adjacent to it. No. 20 appears low when compared with No. 19; but it should be noted that the prismatic coefficient of No. 19 is considerably finer than No. 20, and that, consequently, the performance of No. 19 appears somewhat higher.

The spot, No. 3 on the curve for $\cdot 75\sqrt{L}$, is for a vessel precisely the same as those marked D and E in Table I. (page 185).

The curve for speeds of $1\cdot 05\sqrt{L}$ is entirely for vessels of the "Iris" type, and of the same length. Numerous other examples might be given of vessels of almost similar form; but they are generally shorter and slightly fuller, for both of which reasons they have been left out of consideration, as at these higher speeds slight variations of form or dimension tell very rapidly upon the resistance of the vessel.

The most of the screws of the vessels from whose trial results these curves are drawn are fairly coarse, some having as high a pitch ratio as 1·65.

The ratios in all three curves are for equivalent screws of 1·25 pitch ratio if the actual was other than that. From these curves it appears that for a vessel whose prismatic coefficient is about ·65 and for speeds

of $\cdot 75\sqrt{L}$ the ratio of augmented surface to the disc of a four-bladed screw of the standard type and 1·25 pitch ratio is about 90 for maximum efficiency, and for speeds of $\cdot 85\sqrt{L}$ it is about 80. Vessels of the type whose results are represented by the lower curve and for a speed of $1\cdot 05\sqrt{L}$ will give the maximum performance with a ratio of about 70. These are for trials in smooth water. If there be head winds or other causes to increase the resistance it might appear that an increased disc would be an advantage, as the increased resistance is equivalent to an increase in dimensions of the hull; but against this it is well to note the fact that the vessels, Nos. 14, 16, and 17 of Table V. (page 188), which show superior trial efficiency, also gave better average results in ordinary work than any of the other fully-loaded vessels whose results precede them in the list.

It is not intended to attempt a summary of these results in such a manner as to give other than broad general conclusions as, though the subject has received considerable attention, it is one of such great complexity that without exact data whereby local causes of disturbance, such as abnormal friction, etc., may be eliminated, it is extremely difficult to properly analyse all the data at one's disposal. Without this the only course open is to select such data as are known to have been carefully ascertained and then to deal with broad averages.

So far the following conclusions seem fairly well borne out by the facts:—

1st.—That the data of model experiments are applicable to screws applied to vessels.

2nd.—That the ordinary type of cargo vessel whose prismatic coefficient is from ·75 to ·8 and for speeds of about $\cdot 6\sqrt{L}$ knots, maximum results on trial and in ordinary weather are to be obtained with a screw with 1 square foot of disc area to from 125 to 130 units of augmented or, say, to about 100 square feet of wetted surface, if the standard screw of 1·25 pitch ratio and ·38 surface ratio is adopted. If the screw itself is otherwise proportioned an equivalent modification must be made in these ratios.

3rd.—For finer vessels the ratio of augmented or wetted surface to the screw's disc area may be considerably decreased with advantage.

4th.—Between coarse and fine pitch screws there seems little difference of efficiency when above 1·25 pitch ratio, but that such cases as have been given beneath that seem to indicate a lower efficiency. This may be due to other causes, but it is borne out by model experiments on which many of the calculations are based.

SCREW PROPELLER.

Note on the Modulus of Delivery of a Marine Engine.

1*st*, *Dead Load Friction.*—Results of a few experiments to determine the power absorbed by dead load friction and air pump:—

Mark	Vessel.	Class of Engine.	No. of Cylinders	Ratio of Cylinders.	Working Pressure.	Dead Load Friction		Pumps worked by Engine.	Condition of Engine.	Working Pressure all on L.P. Lbs. per sq. in.	Percentage Dead Load.
						On all Pistons. Lbs. per sq. in.	All on L.P. Lbs. per sq. in.				
					Lbs.						
A	H.M.S. "Iris"	Horizontal compound	2 H.P. 2 L.P.	1; 3·35	65	1·528	1·988	Air pump	Steamed a few times	24·9	8·0
B	Cargo boat	Vertical compound	1 H.P. 1 L.P.	1; 4	90	1·76	2·200	All pumps; Circltng. pump single-acting	First trial	24·7	8·91
C	H.M.S. "Buzzard"	Horizontal triple	1 H.P. 1 I.P. 1 L.P.	1; 2·2 5·4	140	1·974	3·144	Air pump only	Second time steamed	32·8	9·6
D	2nd class cruiser	Vertical triple	do.	1; 2·29 4·9	155	1·43	2·389	do.	do.	38·0	6·3
E	Passenger vessel	do.	do.	1; 2·54 6·31	160	1·75	2·730	All except circltng. pump	First time steamed	34·5	7·91
F	Cargo boat	do.	do.	1; 2·58 7·05	160	1·565	2·360	All; circltng. pump single-acting	do.	32·0	7·38

A. Slide valves.
B. Slide valves, pistons spring packed.
C. H.P. valve, piston type with springs, I.P. and L.P. slides; pistons spring packed.
D. H.P. and I.P. springless piston valves; L.P. slide valve; H.P. and I.P. pistons, single narrow ring, and L.P. lightly packed.
E. H.P. and I.P. springless piston valves; L.P. slide valve; all pistons spring packed.
F. H.P. springless piston valve; I.P. and L.P. slides; L.P. and I.P. lightly packed spring pistons.

It appears from the above that 1·5 to 1·75 lbs. per square inch of gross piston area is ample allowance for dead load friction and the air pump. What percentage this represents upon the ultimate power of the engine depends, of course, upon its mean pressure; but for the purposes of Diagram 1 it has been assumed at 7·8 per cent., being equal to 2·5 lbs. per square inch dead load, and 32 lbs. per square inch working pressure, all applied to the low pressure piston.

2*nd*, *Work absorbed by Pumps.*—A series of examples give for the power developed in the cylinders of the engines working centrifugal circulating pumps 1·3 per cent. of total.

Reciprocating Circulating Pumps.

No.	Class of Engine.	Class of Pump.	Percentage of Power Indicated in Pump.	
1	Two-cylinder compound.	Single-acting	1·92	1·97 mean.
2	" "	" "	2·02	
3	Three-cylinder triple.	Double-acting	1·50.	

FEED PUMPS.—Power indicated in two examples of separate feed pumps:—

Percentage of total	0·605

3rd, Friction of Load.—By a detailed calculation on the basis of a frictional coefficient of ·05, this has been estimated at 6·5 per cent. of the balance of power remaining, after deducting that absorbed by dead load and pumps. Mr. B. F. Isherwood found this by trial (*vide Engineering*, December 31st, 1875, page 525) to be about 7·5 per cent. This figure has been adopted.

Summing up, the modulus of a triple expansion engine working its own pumps is—

Total power indicated		100	
Dead load and air pump	7·8		
Circulating pump	1·5		
Feed pump	·6		
Bilge pump ... ... say	·5		
		10·4	
			89·6
Friction of load $\frac{89·6 \times 7·5}{100}$			6·71
Balance, say 83 per cent.			82·89

Some trials are on record where this modulus cannot have been less than ·85 for a compound engine, the mean pressure, taken as all applied to the low pressure cylinder, being 30 lbs.; and when the pumps are not worked by the engine, the modulus may be still higher.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

SIXTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE SUBSCRIPTION LITERARY SOCIETY, SUNDERLAND, ON FRIDAY EVENING, FEBRUARY 20TH, 1891.

W. THEODORE DOXFORD, ESQ., PAST-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Newcastle, on Monday, February 2nd, which were approved by the members present, and signed by the Past-President.

The PAST-PRESIDENT said that he took the chair because the President was still absent abroad. He was sorry to say there were no new members to propose that evening, the first time that he remembered such an occurrence. He had also to apologise for Mr. Blechynden's unavoidable absence.

The discussion on Mr. A. Blechynden's paper on "The Influence of the Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance" was opened by Mr. E. Hall-Brown, followed by Mr. Hök, and adjourned.

The SECRETARY read a synopsis of Mr. J. T. Nicolson's paper "On the Strength of Short Flat-ended Cylindrical Boilers," the paper itself being taken as read.

Mr. J. C. SPENCE then read a paper on "Results of Experiments on the Strength of Boilers."

DISCUSSION ON MR. BLECHYNDEN'S PAPER ON "THE INFLUENCE OF THE RELATIVE DIMENSIONS AND PROPORTIONS OF THE SCREW PROPELLER ON THE VESSEL'S PERFORMANCE."

Mr. E. HALL-BROWN said the ground covered by Mr. Blechynden's paper was so extensive that it was impossible to do more than touch upon one or two points in the limited time at his disposal. In the first place, then, the basis of the various calculations was the results obtained by experiment, as described in Mr. Blechynden's former paper, and it would be well to see what the value of that data was. As Mr. Blechynden remarked, their ideas of motion were relative, so that it seemed to matter little whether the water moved past the screw or the screw passed through the water, provided that the other conditions were the same, that meant at least that the condition of the water must be the same in both cases, and that the various data could be ascertained with the same degree of accuracy in each case. Were these conditions fulfilled in the experiments upon which Mr. Blechynden relied? He (Mr. Hall-Brown) thought not. The condition of the stream of water arriving at the propeller in Mr. Blechynden's tank would be very different from that acted upon by a propeller driving a phantom ship. In fact, as far as he could see, the condition could not well be more dissimilar, as the water in the tank would be in a state of violent commotion from the action of the sides of the tank, and from the sharp curves at the ends. Again, he failed to see how the actual amount of slip could be ascertained at all accurately, and as this was a basis for certain of Mr. Blechynden's calculations this point was vital. In these remarks he had so far compared Mr. Blechynden's experiments with the conditions of a screw driving a phantom ship. If the comparison were made with a screw driving an actual ship, the difference might be still greater, as the velocity of the stream of water reaching the propeller in the experiment would be least at the tips of the blades, owing to the action of the sides of the tank, while in the case of a screw driving an actual ship the velocity of the water, relative to the screw, would be least at the boss. But it might be urged that Mr. Blechynden produced a number of actual results which showed a remarkable agreement with the results of experiment. Before, however, these results could be accepted they must look to see that nothing superfluous had been included, while at the same time nothing material had been omitted. The modulus of the engine was taken at ·83; this, he did not consider, at all high, and

was, perhaps, a very fair estimate; but as this was the only factor that seemed to be taken into account in applying the results of the tank experiments to actual ships, it would seem that Mr. Blechynden considered that no other modification was necessary, and that other effects neutralised each other, or did not exist. Mr. Froude had enumerated among others two factors of screw propulsion, viz., the thrust-deducted factor and the wake factor, the product of which was, he said, practically unity, and they might be consequently disregarded in practice. He (*Mr. Hall-Brown*) could not agree with this, as it was not borne out in any experiments he knew. He would only instance the "Experiments to Test the Resistance of a First-class Torpedo Boat" made by Mr. A. F. Yarrow, and reported to the Institute of Naval Architects. In these trials the indicated horse-power of the engines, the power absorbed by thrust, and the power exerted at the tow-rope, were all measured and curves constructed. Now, if the wake factor and the thrust deduction factor neutralised each other, the thrust power should have equalled the tow-rope power (neglecting the dead-water resistances which in these boats are very small). As a matter of fact the thrust power exceeded the tow-rope power by from 27·6 per cent. to 16·2 per cent. Now, in these torpedo boats everything was done that experience could suggest to reduce the thrust-deduction factor, and the fact that the thrust exceeded the tow-rope pull in these boats by such a substantial amount as 27·6 per cent. points to the fact that, with ordinary ships, there would be a much larger difference between the thrust and the tow-rope pull. As Mr. Blechynden took no account of this difference he begged to submit that his figures were scarcely such as could be relied upon to prove his case. But another factor of propulsion which seemed to have been entirely lost sight of since it was pointed out by the late Mr. Froude. He referred to dead-water resistances. This form of resistance would be at its minimum in the torpedo boat where it was assumed as these vessels were purposely cut away to reduce the dead water to a minimum; but in an ordinary cargo boat, such as Mr. Blechynden had mentioned in his paper, the effect of dead-water was certainly appreciable, and indeed it was not much greater than would be imagined. What seemed to him very much required was reliable experiments showing the effect of full ships upon the action of the screw propeller. But now let them look very briefly at Mr. Blechynden's methods and figures. In the first place, to use Rule 1, Plate XX., it was required to know the total slip. How was that to be determined, and how had it been obtained in the case of the models experimented on? Taking Mr. Blechynden's estimate of the slip of ships' best propellers as being assessed by them, see what size of propeller

would give that slip in the case of a ship with a speed of 9 knots when indicating 800 indicated horse-power, and taking the slip as given by Mr. Blechynden at 35 per cent., the blades being of the standard shape, and the pitch ratio 1·25. Referring to Fig. 1, Plate XX., they found the value of K was 350. Working out—

$$K = \frac{A^3\ D^2}{I.H.P.},$$

$$D^2 = \frac{K \times I.H.P.}{A^3} = \frac{350 \times 800}{729} \therefore D = \sqrt{383} = 19{\cdot}6.$$

Now, 800 indicated horse-power and 9 knots speed were very common in cargo boats on the North-East Coast, but the diameter of propeller corresponding, by the data given, to 35 per cent. slip, seemed to him very large indeed, and was a marked contrast to some of the propellers advocated by members of this Institution at a former meeting, when, if he remembered correctly, 11 feet 6 inches was spoken of as a suitable diameter of propeller for such a ship. Fig. 4 (Plate XXII.) he did not at all understand. Probably, if Mr. Blechynden answered this question it would remove his difficulty. If a propeller had blades of the standard shape, so that the modulus by Diagram 3 was 1·00, would the pitch ratio have no influence upon the multiplier for K, as found from the Fig. 4? As far as he (Mr. Hall-Brown) saw, the pitch ratio should influence the value of K, but Fig. 4 did not convey this idea to his mind. In conclusion, he begged to give a few figures which showed that screws with a less pitch ratio than 1·25 might be quite as efficient—if the efficiency was measured in the method indicated in the paper—as any given by Mr. Blechynden.

Length.	$\frac{L}{B}$	Prism. Coeffs.	Speed. $\frac{}{\sqrt{\text{Length.}}}$	Wetted Surface / Disc.	W.S. × V³ / I.H.P.	Pitch. / Diam.
282	7 73	·80	·62	106	20,100	1·13
300	7·50	·767	·662	105 5	22,300	1·12
275	7·24	·783	·61	106·	23,700	1·16

These results were from careful progressive trials on the measured mile.

Mr. W. Hök said he would like to ask Mr. Blechynden a few questions with regard to his paper. First, in Table IV. (page 185) there was to be found a column headed "Wake fraction of ship's speed." Did the figures in that column really represent the true value of the speed of the wake? That speed was found, he supposed, by deducting the apparent slip from the experimental slip of the model screw; but would the actual propeller working behind the ship in disturbed water give the same

amount of slip as the model screw in still water? If not, which was very probable, the figures in Table IV. did not represent the true speed of the wake. In Table V. (page 188) Mr. Blechynden had given them the prismatic coefficient of displacement as an indication of the fineness of the ship. He would be much obliged if Mr. Blechynden could see his way to completing that table by adding to it the displacement, the moulded draught, and the I.H.P. of the ships, so as to enable those who used a different mode of thinking to form their own opinion of the value of Mr. Blechynden's deductions. With regard to the prismatic coefficient, he was sorry he was unable to admit that it indicated the fineness of the ship. For instance, a very fine ship with a fine midship section may have the same prismatic coefficient as a very full ship with a full midship section, and yet the former ship was very much finer than the latter. So the sole use of the prismatic coefficient as a guide of fineness was, to his mind, misleading. It was his intention to speak about the influence of the gain from the wake on the loss from the augmentation of resistance, but as Mr. Hall-Brown had discussed that point he would merely state his view, that any theory of the screw propeller, or rather of its application in practice, that did not fully recognise the importance of the reducing, or rather nullifying, influence of the gain from the wake on the augmentation of resistance would not be perfectly sound. Finally, they would notice on page 192 that, according to the writer, if the ship was running at a speed—

$= \cdot 6\sqrt{L}$, the best propeller disc is $= \dfrac{\text{augmented surface}}{130}$;

$= \cdot 75\sqrt{L}$, " " $= \dfrac{\text{augmented surface}}{90}$;

$= \cdot 85\sqrt{L}$, " " $= \dfrac{\text{augmented surface}}{80}$;

$= 1 \cdot 05\sqrt{L}$, " " $= \dfrac{\text{augmented surface}}{70}$.

By a trifling alteration in the value of the rate of disc area per augmented surface, and which was justified by the nature of Fig. 6 (Plate XXIII), it was possible to frame a general formula for calculating the disc area required, this formula being :—

$$\text{Disc area} = \frac{\text{augmented surface}}{75} \times \frac{V}{\sqrt{L}} = \frac{\text{wet surface}}{60} \times \frac{V}{\sqrt{L}},$$

and the concomitant prismatic coefficient—

$$= \frac{\cdot 32}{\left(\dfrac{V}{\sqrt{L}}\right)} + \cdot 25.$$

These expressions do away with the variable rate of propeller disc per augmented or wet surface of ship for different speeds, and link together the speed and the prismatic coefficient, and are therefore more general than the expressions deduced by Mr. Blechynden. If used in conjunction, they give in a very simple manner the most suitable propeller disc when speed, size, and fineness of ship are known.

On the motion of Mr. W. THEODORE DOXFORD, Past-President, the discussion was adjourned till the next General Meeting, to be held in Newcastle-upon-Tyne.

ON THE STRENGTH OF SHORT FLAT-ENDED CYLINDRICAL BOILERS.

By JOHN T. NICOLSON, B.Sc.

[Read before the Institution in Sunderland, February 20th, 1891.]

The following is an investigation (compare Grashof, "Theorie der Elasticität") of the stresses in a cylindrical boiler with flat ends; taking into account the influence of the ends in diminishing the circumferential tension in the shell due to internal pressure. It refutes the erroneous view advanced by Mr. J. C. Spence, in a paper read before the Institution last session, that a serious reduction of the thickness of boiler shells in marine boilers is possible, desirable, and has been overlooked by elasticians. It shows that the reduction of the thickness of shell-plating allowable when the effect of the ends is not as is usual neglected, is inappreciable practically, except for boilers whose length is less than one-third their diameter.

The paper does not discuss the bursting pressure or breaking strength of such boilers; it is limited to the consideration of cases where the stresses and strains in the material are smaller in amount than those at which mutual proportionality ceases; are, *i.e.*, within the so-called elastic limit.

In view of this it is only necessary to add, that many eminent engineers are now agreed that the rational way of estimating the degree of safety of a structure is to compare its working strength with its elastic, rather than with its ultimate strength. It is probably more judicious to fix the working pressure of a boiler as a certain fraction of that which first causes the proportionality of stress and strain in the material to cease, than to fix it as some fraction of the pressure which produces rupture.

In such a boiler let Fig. 1 indicate the direction of the axes of X Y and Z chosen in the discussion of the stresses produced by an internal

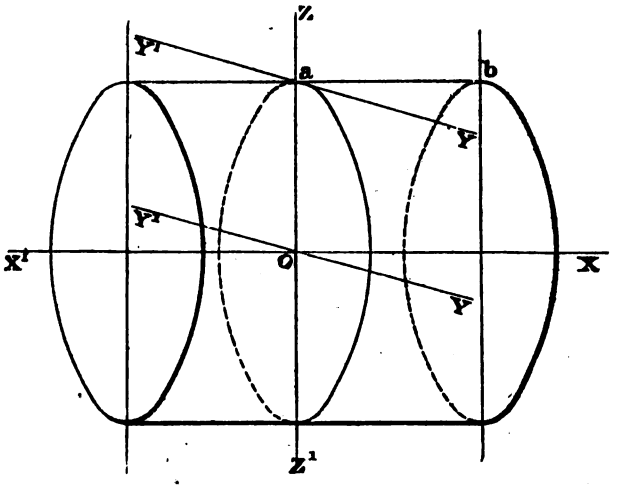


FIG. 1

pressure. If we make a longitudinal section of the shell from *a* to *b* it will in general be of the form shown in Fig. 2 when under pressure (the deflection being, of course, very much exaggerated); the dotted lines indicating its state before strain.

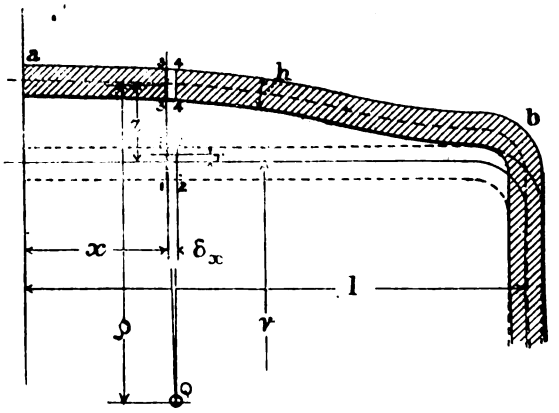


FIG 2

We are about to consider the equilibrium of a plug of metal (shown at 1212, 3434), whose shape is defined (*v*, Fig. 3, Plate XXIV.) by two planes perpendicular to the boiler's axis very close together, δx apart; two planes containing the axis inclined to each other at a very small angle $\delta\phi$; and two co-axial cylinders, the inside and outside of the shell. During strain (as at 3434) this plug is slightly distorted and is kept in equilibrium by the stresses on its

surfaces supplied by the material surrounding it, and by the fluid pressures on its two ends inside and outside the boiler.

If, referring to Fig. 2, we consider the thin slice of boiler shell lying between the two planes which contain the boiler's axis, and which make the infinitesimal angle $\delta\phi$ with each other; we find that it is, in fact, a beam loaded by the uniform internal pressure, p; and supported by being in a manner *encastré* at the ends (the supports being, however, capable of yielding); and by being subjected to tensile stresses acting normally all along its two sides.

Turning now to Fig. 3, Plate XXIV., where OO′ indicates the position and direction of the axis of the boiler; *sss′s′*SSS′S′ a portion of this beam very much enlarged with *nnn′n′* as its neutral surface, and the plug of metal above specified (and obtained from the beam by traversing it with two planes 503 and 60′4, δx apart) is represented by 3434-5656; we must consider at first the equilibrium of only a thin slice of the plug, such as *adhe*, distant v from the neutral surface, and of thickness δv.

Owing to the fact of the deflection of the beam, it is manifest that, in this slice, all such figures as *acdb*, *eghf*, made by planes which contain the axis OO′ cutting the slice, and which before strain were rectangles, have become parallelograms with acute angles at *a*, *d*, *e*, and *h*; and corresponding obtuse ones at *c*, *b*, *g*, and *f*. Shearing stresses τ and τ', τ_1 and τ_1' must therefore be acting in the planes *af* and *gd*, *ec* and *fd*, as shown in Fig. 3, Plate XXIV. On the other hand, the angles in all such figures as *egca* and *fhdb*, made by planes perpendicular to OO′ cutting the slice, have not been altered, so that no shearing stresses are acting on the planes *af* and *gd*, *ad* and *gh* in directions perpendicular to τ, τ', τ_1, and τ_1'. Lastly, no shearing stresses are acting on the planes *ec* and *fd*, *ad* and *eh*; for the angles in all such figures as *abfe* and *cdhg* have remained unchanged.

The stresses acting on the slice are then as follows :—

In the direction of the X-axis: the stresses (tensile, or maybe compressive, when v is negative) σ_x and σ_x' acting on the planes *ag* and *bh*, and the shearing stresses τ and τ' acting on the planes *eb* and *gd*.

In the direction of the Y-axis: the parts of σ_y and σ_y', which we get in that direction by resolving these stresses perpendicular and parallel to the central plane Zoo′ Z′.

And in the direction of the Z-axis: any part (p') of the internal pressure p which may have been transmitted through the plug, so

as now to act directly on the planes *gd* and *eb*; the components of σ_y and σ_y'' in this direction; and the shearing stresses τ_1 and τ_1' acting on the planes *ec* and *fd*.

When the thin slice of material is in equilibrium, we must have the algebraic sums of the stresses multiplied by the areas on which they respectively act—equal to nothing in each of the three axial directions, O X, O Y, O Z. Also, we must have the algebraic sums of the moments of the stresses into the areas they severally affect, taken about the axes, each equal to nothing.

Thus we are able at once to write down the following equations, expressing the conditions of equilibrium of the elemental slice:—

$$(\sigma'_x - \sigma_x)\mathrm{R}\delta\phi\delta v + (\tau' - \tau)\mathrm{R}\delta\phi\delta x = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

$$(\sigma'_y - \sigma_y)\cos\frac{\delta\phi}{2}\,\delta x\delta v = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

$$p'\mathrm{R}\delta\phi\delta x + (\tau_1 - \tau_1')\mathrm{R}\delta\phi\delta v - (\sigma'_y + \sigma_y)\sin\frac{\delta\phi}{2}\,\delta x\delta v = 0 \quad . \quad (c)$$

Where $\mathrm{R} = r' + v = r + z + v$.

If the axes about which moments are taken pass through the centre of figure of the slice, the moments of all stresses are nothing when taken about the X- and Z-axes; but, taken about the Y-axis, the shearing stresses give us for equilibrium the condition expressed, with sufficient accuracy, by—

$$\tau_1\mathrm{R}\delta\phi\delta v\delta x - \tau\mathrm{R}\delta\phi\delta v\delta x = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d)$$

Let us now simplify these equations as far as possible by making use of any further physical considerations which the problem presents, and thus eliminate as many unknown quantities as may be.

Taking first equation (*a*), we have evidently at once $\tau_1 = \tau$, and similarly $\tau_1' = \tau'$; a particular case of the general law in elasticity that the shearing stresses at any point of a strained body which act perpendicularly across the line of intersection of any two planes at right angles to each other are of equal intensity. Thus, wherever τ_1 and τ_1' occur in the other equations (*a*), (*b*), and (*c*), we can put for them τ and τ'.

In equation (*a*) we know that if σ_x alters in amount in passing from the plane *ec* to the plane *fd*, the amount of its change (the rate of such change may be considered uniform for the small length δx) will be the rate of change per unit of length multiplied by the length taken. That is, it will be $\frac{d\sigma_x}{dx}\,\delta x$; so that the stress exerted by the slice at the plane *fd*, in the same sense as σ_x on external matter, will be $\sigma_x + \frac{d\sigma_x}{dx}\,\delta x$. Now,

σ_x', the stress external matter exerts on the slice at the plane *fd*, must be exactly equal and opposite to this, so that the first term in equation (*a*) becomes—

$$(\sigma_x + \frac{d\sigma_x}{dx}\delta x - \sigma_x)\mathrm{R}\delta\phi\delta v.$$

Reasoning in the same way, we find that the second term in that equation becomes—

$$(\tau + \frac{d\tau}{dv}\delta v - \tau)\mathrm{R}\delta\phi\delta x\,;$$

so that, after cancelling and dividing by $\mathrm{R}\delta\phi\delta x\delta v$, equation (*a*) reads :—

$$\frac{d\sigma_x}{dx} + \frac{d\tau}{dv} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Equation (*b*) wholly disappears, for we see from symmetry that $\sigma_y' = \sigma_y$.

In equation (*c*) we cannot tell the value of p', the amount of p the internal pressure which is left after it has been transmitted through all the slides from 54 to *gd*. We must therefore consider the equilibrium in the *z*-direction of all the slices taken together, so as to extend from inside to outside of the shell. We shall then be able to write :—

$$p\left(r' - \frac{h}{2}\right)\delta\phi\delta x + \int_{-\frac{h}{2}}^{+\frac{h}{2}} \frac{d\tau}{dx}\delta x\,\mathrm{R}\,\delta\phi\,\delta v - \int_{-\frac{h}{2}}^{+\frac{h}{2}} 2\sigma_y \sin\frac{\delta\phi}{2}\delta x\delta v = 0\,;$$

where the summation is with reference to v, and is taken between the limits $+\frac{h}{2}$ and $-\frac{h}{2}$; h denoting the shell's thickness. With regard to the first term we note that, as the shell is thin when compared with the boiler's radius, no great error will be introduced by neglecting $\frac{h}{2}$; and hence *à fortiori*, by putting r' for R (*i.e.*, $r' \pm v$) in the second term.

In the third term $\delta\phi$ is so small an angle that $\frac{\delta\phi}{2}$ may be put for sin $\frac{\delta\phi}{2}$, so that the equation may now be written:—

$$pr'\delta\phi\delta x + \int r'\frac{d\tau}{dx}\delta x\delta\phi\delta v - \int \sigma_y\delta\phi\delta x\delta v = 0,$$

or dividing by $r'\delta\phi\delta x$ we finally get:—

$$p + \int_{-\frac{h}{2}}^{+\frac{h}{2}} \frac{d\tau}{dx}\,\delta v - \frac{1}{r'}\int_{-\frac{h}{2}}^{+\frac{h}{2}} \sigma_y\delta v = 0 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Having thus simplified the equations of equilibrium, we have now to examine the nature of the disturbing effects which the stresses acting as

they do simultaneously in different directions on the same element of matter mutually produce.

We know that when a single stress acts so as to extend a specimen in any direction, a contraction takes place in directions perpendicular to that which is proportional to the extension so long as the stress is within the so-called elastic limit. Thus, if σ_x produce a strain e_x in the cube shown (Fig. 4) in the direction of the x-axis, given by the equation:—

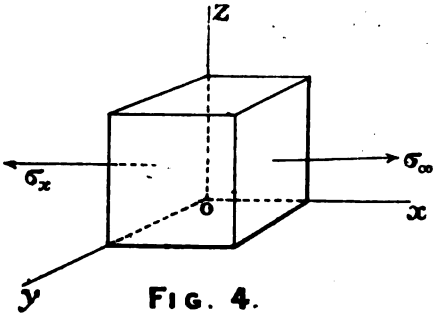


FIG. 4.

$$\sigma_x = \mathrm{E}\, e_x,$$

there will be a strain in the directions of the y- and z-axes of magnitude: $-\frac{e_x}{m}$ and $-\frac{e_x}{m}$ (the material supposed isotropic) where m is found by experiment to be between 3 and 4.

If then, stresses σ_x, σ_y, σ_z, act simultaneously in all three axial directions, we shall have as resulting strains in direction

$$\text{of } x\text{-axis} \qquad e_1 = e_x - \frac{e_y + e_z}{m},$$

$$,, \ y\text{-axis} \qquad e_2 = e_y - \frac{e_z + e_x}{m},$$

$$,, \ z\text{-axis} \qquad e_3 = e_z - \frac{e_x + e_y}{m};$$

or since generally $e = \frac{\sigma}{\mathrm{E}}$,

$$\left.\begin{aligned} \mathrm{E}e_1 &= \sigma_x - \frac{\sigma_y + \sigma_z}{m} \quad \ldots\ldots\ldots (a) \\ \mathrm{E}e_2 &= \sigma_y - \frac{\sigma_z + \sigma_x}{m} \quad \ldots\ldots\ldots (b) \\ \mathrm{E}e_3 &= \sigma_z - \frac{\sigma_x + \sigma_y}{m} \quad \ldots\ldots\ldots (c) \end{aligned}\right\} \qquad (3)$$

Hence, $\sigma_x + \sigma_y + \sigma_z = \frac{m}{m-2}\,\mathrm{E}\,(e_1 + e_2 + e_3) \ldots\ldots$,

but adding to this (3a) and putting s for $e_1 + e_2 + e_3$ we get

$$m\sigma_x + \sigma_x = \frac{m}{m-2}\,\mathrm{E}s + m\mathrm{E}e_1,$$

or

$$\sigma_x = \frac{\mathrm{E}m}{m+1}\left(\frac{s}{m-2} + e_1\right) \ldots\ldots\ldots (a, 4)$$

and, using successively (3*b*) and (3*c*) we get in the same way:—

$$\sigma_y = \frac{Em}{m+1}\left(\frac{s}{m-2} + e_2\right) \quad \ldots\ldots\ldots \quad (b, 4)$$

$$\sigma_z = \frac{Em}{m+1}\left(\frac{s}{m-2} + e_3\right) \quad \ldots\ldots\ldots \quad (c, 4)$$

If we elect to eliminate e_3 from these equations we may get a value for it from (4, *c*), viz.:—

$$e_3 = \frac{(m+1)(m-2)}{Em(m-1)}\sigma_z - \frac{e_1 + e_2}{m-1},$$

and substituting it in (4, *a* and *b*) we get:—

$$\left.\begin{aligned} \sigma_x &= \frac{mE}{m^2-1}(me_1 + e_2) + \frac{\sigma_z}{m-1} \quad \ldots\ldots \quad (a) \\ \sigma_y &= \frac{mE}{m^2-1}(e_1 + me_2) + \frac{\sigma_z}{m-1} \quad \ldots\ldots \quad (b) \end{aligned}\right\} (5)$$

In applying these equations (5, *a* and *b*) to the case in hand, we must find the values of the strains e_1 and e_2 from the geometrical conditions of the problem. Let us then consider the longitudinal section of the boiler shell in Fig. 2 (page 206). If it be supposed that the two originally plane sections of the beam, shown in trace as 11 and 22, remain plane sections when the beam is bent, then the traces of these sections for the bent beam, 33 and 44, will intersect in a point Q, whose distance from the trace of the neutral surface will be ρ, the radius of curvature of the beam at x. Let the strain at the neutral surface nn' (*vide* Fig. 3, Plate XXIV.) due to longitudinal tension of the shell, if any, be denoted by e_0; and that at cd' distant v from nn' by e_1 (since it is in the direction of the x-axis nearly). If the original length, alike of nn' and cd' was δs; then their present lengths are $\delta s + e_0\delta s$, and $\delta s + e_1\delta s$, respectively. But these lengths being arcs of concentric circles (for a very short distance) are proportional to the radii of those circles ρ and $\rho + v$,

or $$\frac{\delta s\,(1 + e_1)}{\delta s\,(1 + e_0)} = \frac{\rho + v}{\rho}.$$

Hence $$1 + e_1 = 1 + e_0 + \frac{v}{\rho} + \frac{v}{\rho}e_0,$$

or $$e_1 = e_0 \pm \frac{v}{\rho} \quad \ldots\ldots\ldots \quad (6)$$

{since $\frac{v}{\rho}e_0$ is negligible, and the reasoning holds for v negative.}

But if z be the deflection of the neutral surface (v, Fig. 2), we know that:—

$$\frac{1}{\rho} = \mp\frac{d^2z}{dx^2} \text{ (very nearly)} \quad \ldots\ldots \quad (7)$$

where the upper or lower sign must be taken according as the centre of curvature is within or without the shell. So that in all cases:—

$$e_1 = e_0 - v\frac{d^2z}{dx^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

In order to find e_2, the strain in the direction of the y-axis (*i.e.*, perpendicular to the plane of the paper in Figs. 2 and 3), we have only to think that the circle described about the axis of the boiler with its plane perpendicular thereto, and passing through c (Fig. 3), was formerly of a length $2\pi(r \pm v)$, and is now of a length $2\pi(r' \pm v)$ or $2\pi(r + z \pm v)$; the elongation it has experienced is $2\pi z$, and the strain $\frac{2\pi z}{2\pi(r \pm v)}$, which can be put $= \frac{z}{r}$ since the thickness of the shell and *à fortiori* v is small compared with r.

Thus

$$e_2 = \frac{z}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In the two equations (5, a) and (5, b) we have now left only one unknown quantity on the right-hand side, viz., σ_z. This stress we find on examination to be so small as to be negligible, for it is produced, firstly, by the direct transmission of the internal pressure, p, up through the slices of the plug (v, Fig. 3, Plate XXIV.) until it is entirely equilibrated; and, secondly, as the result of the contraction (or extension) in the z-direction caused by the tensile (or compressive) stresses in the x- and y-directions.

Now, in this investigation we must limit ourselves to the cases where no stress whatever is greater than that corresponding to the elastic limit of the material; wherefore it follows that the effect of p, as a direct crushing stress, and as forming the first part of σ_z, is negligible since σ_y approaches the elastic limit with only small values of p. And, further, the second part of σ_z may be neglected with the same immunity from error as we obtain in leaving out of account the transverse stress induced in a bar when it is subjected to longitudinal tension.

Putting, therefore, the terms involving σ_z in equations (5, a and b) equal to nothing, and substituting in them for e_1 and e_2, their values as given in equations (8) and (9), we get:—

$$\sigma_x = \frac{m\mathrm{E}}{m^2-1}\left(me_0 - mv\frac{d^2z}{dx^2} + \frac{z}{r}\right)$$

$$= \frac{m\mathrm{E}}{m^2-1}\left(me_0 + \frac{z}{r}\right) - \frac{m^2\mathrm{E}}{m^2-1}v\frac{d^2z}{dx^2} \quad . \quad . \quad . \quad . \quad (11^1)$$

where $\frac{m\mathrm{E}}{m^2-1}\left(me_0 + \frac{z}{r}\right)$ is evidently the (longitudinal) stress at the

neutral surface or mean radius of the shell, being the value of σ_x when $v = o$. If F be the sectional area of the shell (made by a plane perpendicular to the axis), and P the load upon it due to pressure on the boiler ends—

$$\sigma_x = \frac{P}{F} - \frac{m^2}{m^2-1} E v \frac{d^2z}{dx^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

and

$$\sigma_y = \frac{mE}{m^2-1}\left(e_0 - v\frac{d^2z}{dx^2} + m\frac{z}{r}\right)$$

$$= \frac{1}{m}\frac{P}{F} + \frac{Ez}{r} - \frac{m}{m^2-1} E v \frac{d^2z}{dx^2} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

We must now revert to our reduced equations of equilibrium (1) and (2), in which we proceed to substitute the expressions obtained for σ_x and σ_y in equations (11) and (12). Equations (1) and (2) are :—

$$\frac{d\sigma_x}{dx} + \frac{d\tau}{dv} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and

$$p + \int_{-\frac{h}{2}}^{\frac{h}{2}} \frac{d\tau}{dx}\delta v - \frac{1}{r}\int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_y \delta v = 0 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In the first of them we have by differentiation of (11)—

$$\frac{d\sigma_x}{dx} = -\frac{m^2}{m^2-1} E v \frac{d^3z}{dx^3}.$$

Therefore,

$$\frac{d\tau}{dv} = \frac{m^2}{m^2-1} E v \frac{d^3z}{dx^3},$$

and by integration

$$\tau = \frac{m^2}{m^2-1} E \frac{v^2}{2}\frac{d^3z}{dx^3} + f(x) \quad . \quad . \quad . \quad . \quad (13)$$

To determine $f(x)$ we know that when $v = \pm\frac{h}{2}$, $\tau = 0$. Thus

$$f(x) = -\frac{m^2}{m^2-1} E \frac{h^2}{8}\frac{d^3z}{dx^3}.$$

And finally,

$$\tau = -\frac{m^2}{m^2-1} E \frac{h^2 - 4v^2}{8}\frac{d^3z}{dx^3} \quad . \quad . \quad . \quad . \quad (14)$$

Thus, in equation (2) since—

$$\frac{d\tau}{dx}\delta v = -\frac{m^2}{m^2-1} E \frac{h^2-4v^2}{8}\cdot\frac{d^4z}{dx^4}\delta v$$

$$\int_{-\frac{h}{2}}^{\frac{h}{2}} -\frac{m^2}{m^2-1} E \frac{d^4z}{dx^4}\frac{h^2-4v^2}{8}\delta v = -\frac{m^2}{m^2-1} E \frac{h^3}{12}\frac{d^4z}{dx^4}$$

$$\left(\text{for } \int_{-\frac{h}{2}}^{\frac{h}{2}} v^2\delta v = \frac{1}{3}\left(\frac{h^3}{8} + \frac{h^3}{8}\right) = \frac{h^3}{12};\right.$$

$$\left.\text{and } \int_{-\frac{h}{2}}^{\frac{h}{2}} \left(\frac{h^2}{8} - \frac{v^2}{2}\right)\delta v = \frac{h^3}{8} - \frac{h^3}{24} = \frac{h^3}{12}\right);$$

also $\frac{1}{r'}\int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_y \delta v = -\frac{1}{r'}\int_{-\frac{h}{2}}^{\frac{h}{2}} \left(\frac{1}{m}\frac{P}{F} + \frac{Ez}{r} - \frac{m}{m^2-1} Ev \frac{d^2z}{dx^2}\right)\delta v$

$$= -\frac{1}{r'}\left(\frac{1}{m}\frac{P}{F} + E\frac{z}{r}\right)h, \qquad \left(\text{for} \int_{-\frac{h}{2}}^{\frac{h}{2}} v\delta v = 0\right).$$

Thus, equation (2), after changing signs, now reads (putting r for r^1, which we now see can be done, the error incurred within the limits of elasticity being very small):—

$$\frac{m^2}{m^2-1} E\frac{h^3}{12}\frac{d^4z}{dx^4} + \frac{Eh}{r^2} z + \frac{Ph}{rmF} - p = 0 \quad . \quad . \quad (15)$$

or $$\frac{d^4z}{dx^4} + 12\frac{m^2-1}{m^2}\frac{z}{r^2h^2} = 12\frac{m^2-1}{m^2}\frac{1}{Eh^3}\left(p - \frac{Ph}{mFr}\right). \quad (16)$$

or $$\frac{d^4z}{dx^4} + bz = B \; . \; . \; . \; . \; . \; . \; . \quad (17)$$

Now, putting $z = \frac{B}{b} + u$, where B and b do not involve x, but u is a function of x, we may write (17):—

$$\frac{d^4u}{dx^4} + B + bu = B,$$

$$\text{or} \quad \frac{d^4u}{dx^4} + bu = 0 \; . \; . \; . \; . \; . \; . \quad (18)$$

Here b is $\frac{12(m^2-1)}{m^2r^2h^2}$; B is $\frac{12(m^2-1)}{m^2}\frac{1}{Eh^3}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right)$; and $\frac{B}{b} = \frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right)$.

Thus, $$z = \frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right) + u$$

$$= A + u, \text{ say} \; . \; . \; . \; . \; . \; . \; . \; . \quad (19)$$

If we put $a = \sqrt[4]{\frac{3(m^2-1)}{m^2r^2h^2}}$; then $4a^4 = \frac{12(m^2-1)}{m^2r^2h^2}$; and with this value for a, (18) may be written, for purposes of solution :—

$$\frac{d^4u}{dx^4} + 4a^4u = 0 \quad . \; . \; . \; . \; . \quad (18^1)$$

The solution of this equation (v, Appendix) is :—

$$u = \frac{A_o(\epsilon^{ax} + \epsilon^{-ax})}{2}\cos ax + \frac{B_o(\epsilon^{ax} - \epsilon^{-ax})}{2}\sin ax \quad (19)$$

Whence we obtain—

$$z = \frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right) + A_o \cosh ax \cos ax + B_o \sinh ax \sin ax \quad (20)$$

putting $\cosh ax$ for $\frac{\epsilon^{ax} + \epsilon^{-ax}}{2}$, and $\sinh ax$ for $\frac{\epsilon^{ax} - \epsilon^{-ax}}{2}$.

When $x = l$ (the half length of the boiler), $z = 0$, and $\frac{d^2z}{dx^2} = 0$.

But $\frac{d^2z}{dx^2} = 2a^2 (- A_o \sinh ax \sin ax + B_o \cosh ax \cos ax)$.

Hence $\frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right) + A_o \cosh al \cos al + B_o \sinh al \sin al = 0$,

and $\qquad - A_o \sinh al \sin al + B_o \cosh al \cos al = 0$.

From which we obtain the values of the constants :—

$$A_o = -\frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right)\frac{\cosh al \cos al}{\sinh^2 al \sin^2 al + \cosh^2 al \cos^2 al},$$

$$B_o = -\frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right)\frac{\sinh al \sin al}{\sinh^2 al \sin^2 al + \cosh^2 al \cos^2 al}.$$

But since $\sin^2 al = 1 - \cos^2 al$, and $\sinh^2 al = \cosh^2 al - 1$, the denominator reduces to—

$$\text{Cosh}^2 al - \cos^2 al = \frac{1}{2}(\cosh 2\,al + \cos 2\,al).$$

So that finally,

$$A_o = -\frac{2r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right)\frac{\cos h\,al \cos al}{\cos h\,2\,al + \cos 2\,al} \quad . \quad . \quad (21)$$

and

$$B_o = -\frac{2r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right)\frac{\sinh al \sin al}{\cosh 2\,al + \cos 2\,al} \quad . \quad . \quad (22)$$

Knowing now A_o and B_o, equation (20) gives z ; and equation (12) gives σ_y (the circumferential stress) for the various values of x from o to l. In particular, when $x = 0$; *i.e.*, at the middle of the boiler's length :—

$$\sigma_y = \frac{P}{mF} + \frac{r}{h}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right) + \frac{EA_o}{r} \quad . \quad . \quad . \quad . \quad . \quad (23)$$

If the pressure on the flat boiler ends be taken by stays so that there is no longitudinal strain, e_o, on the shell ; $\frac{P}{F} = 0$, and

$$\sigma_y = \frac{p}{h} + \frac{E}{r} A_o$$

$$= \frac{pr}{h}\left(1 - \frac{2\cosh al \cos al}{\cosh 2\,al + \cos 2\,al}\right) \quad . \quad . \quad . \quad . \quad . \quad (24)$$

This is the case the author has chosen for numerical calculation ; taking different values of the ratio $\frac{l}{r}$. He chose a boiler 15 feet in diameter, with an internal pressure of 160 lbs. per square inch above the atmosphere, and of five different lengths, varying from 1 to 15 feet.

He found the ratio of the actual circumferential tensile stress at the middle of the length, to what it would be with open ends, or as it is usually calculated, to be as follows :—

Boilers, all 15 feet diameter ; length =	1 foot	2 feet	5 feet	10 feet	15 feet
Ratio of length to diameter =	$\frac{1}{15}$	$\frac{2}{15}$	$\frac{1}{3}$	$\frac{2}{3}$	1
$\frac{\sigma_y}{\frac{pr}{h}}$ = $\frac{\text{actual stress at middle}}{\text{stress as usually calculated}}$ =	·2008	·8913	·9410	·9985	·9999

Showing that the permissible reduction of scantling in the middle strake of plating is quite miscroscopic for ordinary marine boilers. It will be noticed that these results have been obtained by putting $z = 0$ in equation (20), by supposing, that is to say, that the boiler ends give a rigid support—a supposition which gives less circumferential stress in the centre than that which actually obtains. The extensibility of the ends will reduce still more the assistance they afford the shell in withstanding internal pressure.

APPENDIX.

The differential equation—

$$\frac{d^4u}{dx^4} + 4a^4u = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)^1$$

has for its general solution—

$$u = C_1\epsilon^{c_1x} + C_2\epsilon^{c_2x} + C_3\epsilon^{c_3x} + C_4\epsilon^{c_1x} \quad . \quad . \quad . \quad . \quad . \quad (a)$$

for, assuming that $u = C\epsilon^{cx}$, we find that—

$\frac{d^4u}{dx^4} = c^4C\epsilon^{cx}$; and $(18)^1$ may be written—

$$c^4C\epsilon^{cx} + 4a^4C\epsilon^{cx} = 0 ;$$

$$\text{or, } c^4 + 4a^4 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

the four roots of which determine the four different values of c, each of

which makes $u = Ce^{cx}$ a solution of the equation given. If $c_1\ c_2\ c_3\ c_4$ are these four roots, we have the system of particular solutions—

$$u = C_1e^{c_1x},\ u = C_2e^{c_2x},\ u = C_3e^{c_3x}, \text{ and } u = C_4e^{c_4x},$$

whence* the general solution above (a).

The roots of $c^4 = -4a^4 = -1 \times 4a^4$ are imaginary; and of the form, $m \pm ni$, $m^1 \pm n^1i$ (where $i = \sqrt{-1}$), for $c = \sqrt[4]{-1} \times \sqrt{2a}$, and the four-fourth roots of -1, are :—

$$\pm \frac{1 \pm i}{\sqrt{2}}.\dagger$$

Thus the four roots of the equation $c^4 + 4a^4 = 0$ are :—

$$\left.\begin{aligned} c_1 &= m + ni = a + ai, \\ c_2 &= m - ni = a - ai, \\ c_3 &= m^1 + n^1i = -a + ai, \\ c_4 &= m^1 - n^1i = -a - ai, \\ \text{whence } m &= a \quad n = a \\ m^1 &= -a \quad n^1 = a \end{aligned}\right\} \quad \ldots\ldots (c)$$

Putting in the values of $c_1\ c_2\ c_3\ c_4$ in the general solution—

$$u = C_1e^{(m+ni)x} + C_2e^{(m-ni)x} + C_3e^{(m^1+n^1i)x} + C_4e^{(m^1-n^1i)x}$$
$$= e^{mx}(C_1e^{nix} + C_2e^{-nix}) + e^{m^1x}(C_3e^{n^1ix} + C_4e^{-n^1ix}).$$

Now, $$e^{inx} = \cos nx + i \sin nx,$$

and $$e^{-inx} = \cos nx - i \sin nx,$$

for putting successively nxi and $-nxi$ for x in the expansion of e^x in powers of x, viz.:—

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{2\cdot3} + \frac{x^4}{2\cdot3\cdot4} + \ldots\ldots;$$

adding and subtracting, we get—

$$e^{nxi} + e^{-nxi} = 2\cos nx \quad \ldots\ldots (1)$$

and $$e^{nxi} - e^{-nxi} = 2i \sin nx \quad \ldots\ldots (2)$$

adding and subtracting (1) and (2) we have

$$e^{nxi} = \cos nx + i \sin nx,$$

and $$e^{-nxi} = \cos nx - i \sin nx. \qquad \text{(Q.E.D.)}$$

Therefore

$$u = e^{mx}\left\{(C_1 + C_2)\cos nx + (C_1 - C_2)\,i \sin nx\right\}$$
$$+ e^{m^1x}\left\{(C_3 + C_4)\cos n^1x + (C_3 - C_4)\,i \sin n^1x\right\}$$

* *V.* Boole, chap. ix., art. 4.
† *V.* Chrystal's *Algebra*, I., p. 237, or Todh. *Alg.*, p. 218.

or, putting f for $C_1 + C_3$, g for $(C_1 - C_3)\,i$;
f^1 for $C_2 + C_4$, g^1 for $(C_2 - C_4)\,i$;

$$u = e^{mx}(f\cos nx + g\sin nx) + e^{m^1x}(f^1\cos n^1x + g\sin n^1x) \quad . \quad . \quad . \quad . \quad (d)$$

Let us now insert for m and n, m^1 and n^1, their values as given in equation (c) obtained from the solution of equation (b), then (d) will read :—

$$u = e^{ax}(f\cos ax + g\sin ax) + e^{-ax}(f^1\cos ax + g^1\sin ax) \quad . \quad (d^1)$$

Since the deflection of the beam (described in Fig. 2) is the same for the same values of x on the right and left side of the central plane, we must have :—

$$e^{ax}(f\cos ax + g\sin ax) + e^{-ax}(f^1\cos ax + g^1\sin ax) = e^{-ax}(f\cos(-ax) + g\sin(-ax)) + e^{ax}(f^1\cos(-ax) + g^1\sin(-ax)).$$

But $\cos(-ax) = \cos(ax)$, and $\sin(-ax) = -\sin(ax)$,

we have therefore :—

$$e^{ax}(f\cos ax + g\sin ax) + e^{-ax}(f^1\cos ax + g^1\sin ax) = e^{-ax}(f\cos ax - g\sin ax) + e^{ax}(f^1\cos ax - g^1\sin ax)$$

for every value of x, which gives us

$$f\cos ax + g\sin ax = f^1\cos ax - g^1\sin ax$$

and

$$f^1\cos ax + g^1\sin ax = f\cos ax - g\sin ax,$$

from which we see at once by addition and subtraction that $f = f^1$ and $g = -g^1$; so that

$$u = (e^{ax} + e^{-ax})f\cos\overline{ax} + (e^{ax} - e^{-ax})g\sin\overline{ax};$$

or, finally, from equation (19).

$z = A + f(e^{ax} + e^{-ax})\cos\overline{ax} + g(e^{ax} - e^{-ax})\sin\overline{ax}$, or putting in the value of A from (19) and substituting for f and g two new constants, A_o and B_o, equal to $2f$ and $2g$ respectively, we write :—

$$z = \frac{r^2}{Eh}\left(p - \frac{1}{m}\frac{P}{F}\frac{h}{r}\right) + A_o\frac{e^{ax} + e^{-ax}}{2}\cos\overline{ax} + B_o\frac{e^{ax} - e^{-ax}}{2}\sin\overline{ax} \quad . \quad . \quad . \quad . \quad (20)$$

which is equation (20).

RESULTS OF EXPERIMENTS ON THE STRENGTH OF BOILERS.

By J. C. SPENCE.

[Read before the Institution in Sunderland on February 20th, 1891.]

Last year the author brought before this Institution an argument intended to show that the present system of calculating the strength of boilers is erroneous, and proposed a new method.

Since then he has made a series of experiments on the subject, the results of which he now desires to place before the Institution.

His previous argument was, that it was unnecessary to make a boiler as strong as if it were an endless ring, and that the resistance, due to the connection between shell and ends, should be added to the circumferential resistance of the shell in order to get the true strength of the structure. If this were true, the strength of boilers, especially of the marine type, would not be, as hitherto assumed, independent of their length, but would depend, as much on their length as on their diameter. To test this, he made three small cylinders, (Figs. 1, 2, and 3, Plate XXV.) of equal diameter, thickness of plate, etc., differing only in length, and tested them to destruction by water pressure. Each of these drums was made of a sheet of $\frac{3}{16}$ inch steel plate rolled to a circle of 26 inches diameter, with one longitudinal single riveted joint. The ends were flanged outwards and riveted to strong end plates which were very strongly stayed, longitudinal and end joints were single riveted, pitch of rivets $1\frac{1}{4}$ inches, diameter of rivets $\frac{1}{2}$ inch, diameter of holes $\frac{9}{16}$ inch, all drilled in place; percentage of plate in line of rivet holes, 55 per cent. of solid plate. The riveted joint was adopted because the only other alternative that occurred to him was a welded seam, and he considered that a known weakness was better than an unknown strength. The single riveted joint was adopted in order to keep the pitch of rivets small, and give the thin plate a chance

of being water-tight with ordinary caulking. The end attachment was made, in the style shown, to keep all the rivets outside, and avoid the necessity for any hand holes in end or shell.

EXPERIMENTS.

No. 1 *Model.*—The working pressure of all these models being, according to standard rule, 80 lbs., Model No. 1 was, after completion, tested and made tight to a test pressure of 160 lbs. before any measurements were taken. Five circles were then drawn round the shell as shown in Fig. 1, Plate XXV.; these were marked off at the points $a_1 b_1$ $a_2 b_2$, etc., in order that the extension of joint might be observed separately from the extension of solid plate. Measurements were taken from a to b across the joint by a pair of compasses, and from b to a round the shell by a steel tape. Pressure was raised by means of a small hand test pump. Measurements of joint and plate were taken at various pressures and are given in Table VIII. (page 232), the pressure being reduced to 0 from time to time. Up to 600 lbs. pressure the model was not seriously strained, the leakage looked considerable but the amount could not have been great, as an occasional stroke of the hand pump was sufficient to keep the pressure constant for a considerable time while all the measurements were made and checked and recorded. As the pressure rose above this, the leakage increased rapidly, and not more than 630 lbs. could be got with the hand pump. At this pressure the joint was evidently strained, but in other respects the model was not appreciably altered. The experiment was then stopped, the joints and rivets were all caulked and the model was carried into the boiler shop and connected to the hydraulic service pipes. Pressure was raised to 700 lbs. by a pair of steam pumps, but this could not be increased owing to leakage. Two other pumps were then coupled on, but were still unable to increase the pressure, the model still remaining not seriously damaged. A connection was then made with the accumulator, and the pressure rose to 730 lbs.; the form of model visibly altered, and again the leakage overpowered the whole supply of water. The form taken by the model is shown by the dotted lines A B in Fig. 1, Plate XXV., which shows a decided hump near to each end and a slight hollow in between.

Model No. 2.—Was tested in much the same manner as No. 1. The leakage overpowered the hand pump at 550 lbs. pressure; joints and rivets were then caulked and model connected to hydraulic service pipes.

In this case four pumps were discharging into the accumulator, and the pressure was admitted from thence to model. Pressure was allowed to increase gradually till it reached 680 lbs.; the model then visibly changed form, and the leakage overpowered the water supply. The form taken is shown in Fig. 2, Plate XXV., which closely resembles that of No. 1.

Model No. 3.—This model had only three lines drawn on it, and had not been tested previous to the experiments; it was therefore thought advisable to caulk up some slight leaks which showed themselves at 250 lbs. pressure. This was done; the pressure was then increased by the hand pump to 550 lbs., when the leakage balanced the supply of water. The model was then caulked all over and connected to the accumulator. The pressure was raised quickly to 800 lbs.; at that pressure the joint broke with a loud report. The form taken by the model is shown in Fig. 3, Plate XXV., the two outer curves showing the form taken by the plate all round the circle, except in the immediate region of the joint, where the barrelling is most pronounced, as shown by the curve at centre of Fig. 3.

All the facts and figures observed during the experiments are given in the Tables Nos. VIII., IX., X., XI., and XII. (see pages 232 to 236), and drawings (Plate XXV). But facts and figures are of little use and may be very misleading until the laws which govern them are understood. And if the author could give a clear and definite explanation of the results of his experiments, he would feel that he had done some service; but he fears that he may have only succeeded in unsettling established principles without being able to offer anything definite in their place.

Although he has not been able to deduce a clear relation between pressure and strain, yet, as he has given a good deal of attention to this problem, and made some steps towards its solution, he has recorded the partial solution worked out by him. As the arguments are too speculative to affect practical work he has given them in an Appendix (page 225); and he now only proposes to notice a few facts, to prove that there is a problem to solve, and attempt to extract some practical guidance from these experiments.

In the first place he would like to call attention to the points that appear to him to be most significant.

No. 1 was the first model tested, and he was surprised to find that the first measurable alteration was a contraction at the joints. This remarkable result is not easily reconciled with the theory that the shell was subject to a uniform tension and to no other strain. He had searched

through many records of tests to find if this was unusual, but could find very little directly bearing on it. Some few facts pointed to a similar action in other cases, but they were too indirect for quoting.

The next point worthy of notice is the very high pressure, 730 lbs. to the inch, sustained by this model. On the endless ring hypothesis the breaking strain of the joint would be reached at a pressure of 506 lbs.; its elastic limit at a pressure of 328 lbs; the elastic limit of the solid plate being 586 lbs. (See Table XI., page 235.) Those who are familiar with the sudden and rapid elongation which occurs when steel of this character reaches its elastic limit will probably agree that, in this experiment, that limit had not been reached (at any rate in the plate) till the pressure was about 700 lbs., and had not been much passed at 730 lbs.

Another curious fact was, that the joint, except by leakage, did not appear to have suffered more than the solid plate. Fig. 4, Plate XXV., shows the form of the model at the place where it was most strained. It will be seen that this is very nearly circular, and should be compared with Fig. 5, Plate XXV., which shows the form of Model No. 3, in which the joint and the plate near the joint show signs of much greater distress than the rest of the plate. Seeing that the joint has only 55 per cent. of the strength of the plate against circumferential tension, this behaviour suggests the idea that plate and joint were not bulged by circumferential tension, but by a radial strain acting normally to the circumference.

The most striking result is the fact that the form finally assumed was rather hollow in the centre. Uniform circumferential tension would, one would expect, produce a straight line, or one rather arched like that of Fig. 3, as the effect of ends would gradually diminish.

Even a strain normal to the circumference which bulged up the points A and B would, if acting alone, also lift up the line between A and B and keep it parallel.

The form exhibited here seems then to indicate a distribution of strain in the shell in which the strain increases as the distance from the centre increases.

The question at once arises—Is this behaviour singular or in accordance with general law? The writer has not been able to find much evidence bearing directly on this point, but on looking through tables of boiler explosions, it will be noted, that a large proportion have given way at the end seams. The experiments made last year by Mr. Scott, at Greenock, afford the most beautiful illustration of this curious phenomenon. It will be noticed that the short cylinder, No. 3, has hogged, while the longer ones, No. 1 and No. 2, have sagged at the centre.

Now, by looking at Fig. 6, Plate XXV., which is laid down from the dimensions given by Mr. Scott, and shows the form assumed by his experimental boiler at a pressure of 580 lbs., it will be seen that each of the short cylinders between the seams have hogged, but that the cylinder as a whole is much less stretched at the centre than at the ends. This form, strange as it may appear, is therefore not exceptional; it reappears in Model No. 2, but not in No. 3.

No. 3 was the second model tested. Judging from its behaviour under pressures obtained by the hand pump it appeared to be decidedly weaker than No. 1; still, it stood 10 per cent. more than the breaking strength of joint without serious damage. When connected to accumulator the pressure was raised very quickly. So far as the eye could detect, the form of the model remained unaltered till near the point of rupture, the bulging of the shell and the bursting of the joint being nearly simultaneous, as far as he could judge. In this case the joint and the plate near the joint were evidently more strained than the rest of the plate. The radius at the joint was about $14\frac{3}{8}$ inches, and if it were true that the strain on the joint was radius $\times$ pressure, then this joint must have ruptured at a strain about 77 per cent. greater than its calculated strength.

Model No. 2 appeared to be intermediate in strength between No. 1 and No. 3. It showed that the form assumed by No. 1 was not the result of accident, but of some general law. The results, being intermediate between 1 and 3, serve as a general confirmation of both.

The writer thinks he has now brought forward sufficient evidence, to prove that the strength of cylindrical boilers is still an unsolved problem. And he repeats, what he has formerly stated before this Institution, that a true solution of the problem will apply equally to boiler shells subject to internal and to flues subject to external pressure.

The generally accepted theory which treats boiler shells as endless rings cannot be right, and is not even an approximation to the truth in these experiments. The theory proposed by the author last year cannot be right, or No. 3 Model would have stood nearly twice the pressure of No. 1, and Nos. 1 and 2 would not have yielded near the end joint, but at these joints. Neither of these theories can therefore be true, they both contain an element of truth and an element of error. The first theory appears to be nearly right in making the strength of boilers depend on a ratio between diameter and thickness. The second theory, which assumes that the strain on the ends is not a small factor to be neglected, is confirmed by the evidence of straining near the ends. If these ends had

been closed by a relatively weak tube plate full of holes instead of by these strong plates, it is the author's opinion that the weak tube plates would have yielded before the plate bulged, and he cannot believe that the original straight lines of these cylinders can have altered to either of the forms, shown in Figs. 1 and 2, or Fig. 3, Plate XXV., without being stretched longitudinally; or that they could stretch longitudinally without overcoming a great resistance, which should be added to the resistance of plate to circumferential stretching. If, then, the errors could be eliminated, and the truth contained in these two theories combined, a true theory might be evolved from the process. The writer does not think this question can be settled by mathematics, but a few experiments made in a systematic manner would probably show, quite near enough for all practical work, what pressure can safely be used in any given boiler.

It is the writer's opinion that the experiments already made are sufficient to justify some alteration in our practice. All the models referred to stood a pressure of more than 540 lbs. with the small hand test pump. It cannot be far wrong to assume that this pressure had not strained them beyond their elastic limit. It would therefore be perfectly safe to make the test pressure for these, two-thirds of 540 lbs. = 360 lbs., and the working pressure one-half of that, say 180 lbs. According to current practice the working pressure is only 80 lbs., and if 180 lbs. is quite safe, then in this case our rules are wrong to the extent of 125 per cent.

If, as he believes, all those models yielded by bulging the solid plate and not by tearing the joint, then it follows that they would not have been stronger if the joints had been, as in boiler work they generally are, over 80 per cent. of the strength of the solid plate instead of only 55 per cent. With a joint of over 80 per cent. the working pressure would be, according to present practice, about 120 lbs.; if 180 lbs. is a safe pressure, then in such a case the error in the present rules is 50 per cent.

The working pressure of these models, if calculated by the current rules, only substituting the strength of solid plate for that of joint, is about 150 lbs. This is still below the working pressure deduced from experiment, and he believes that it would now be quite safe to take the strength of solid plate as our basis instead of the joint, to keep other constants unaltered, and arrange our riveting with a view to tightness and caulking, without any regard to percentage of strength, provided that percentage was not reduced below 55. This would mean that with the same thickness of shell plates, the pressure might be increased 25 per cent., or that the same pressure might be carried with the thickness of

shell plates reduced 20 per cent. This he considers a result of some importance, and future experiments may show that still further reductions might be safely made.

From a practical point of view there can be no question that, with the large boilers and high pressures now general, any reduction in thickness of shell plates, which does not involve a reduction in the factor of safety, is a benefit. If an inch plate is enough for strength, then, for many practical reasons, that plate is better than a plate $1\frac{1}{4}$ inches thick. This, of course, does not apply to all sizes and pressures. No one would think of using a $\frac{3}{16}$ inch plate for a steam dome, for instance; a much thicker plate would be used for other reasons, entirely apart from the question of strength. Still, it is well to know what are the requirements of strength. Although they are by no means the only requirements which affect our designs, they always form a factor in the case about which it is better to know the truth than to be contented with an error.

He regrets that he is not in a position to make a more exhaustive set of experiments, for he believes that there is a rich vein of discovery in this line. These experiments seem to prove that our present rules may be wrong to an extent anything between 50 and 125 per cent. It also seems to him that our rules as to boiler flues are simply absurd. It is not possible that their strength can vary inversely as their length; it is quite impossible that it can vary as the square of their thickness.

Before concluding he wishes to record his thanks to Mr. Alexander Taylor, for sharing the expense of these experiments; and to Messrs. B. G. Nichol, J. Sanders, and J. F. Walliker, for making and recording the measurements given in these tables; to Mr. Burrell for tests of plates and joints. He has also to thank his employers, Messrs. the Tyne Boiler Works Company, Limited, for the use of their plant and machinery free of charge.

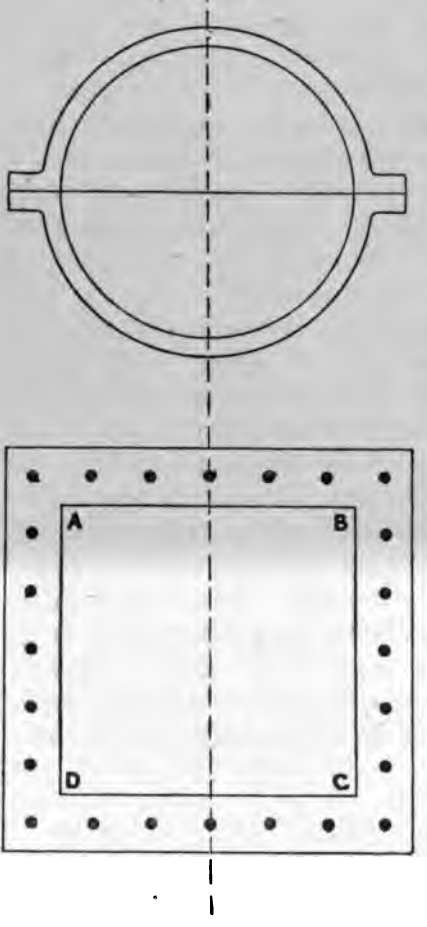
APPENDIX.

The basis of the author's former paper on this subject was the proposition, that if a cylinder be made in two halves, bolted together at the centre, as in Fig. 7, the tensile strain on the bolts in the flanges, due to any pressure in the cylinder, is absolutely independent of the form of the vessel. It depends only on the area of A B C D and the pressure, and remains the same if one of the halves of the cylinder is removed and re-

placed by a flat plate, or by a half cylinder with its axis at right angles to the bottom half, or by any other shaped cover, provided that cover is strong enough to transmit the pressure on it to the bolts.

That this proposition is axiomatic did not then, and does not now, appear to him to be a question about which there can be any difference of opinion amongst engineers. Neither does it appear doubtful, that if the two halves of this vessel were joined together without flanges, by the shell and end plates being continuous, that the strain on these plates must be the same in amount and distribution as on the bolts.

FIG. 7.



To one saturated with the theory that the strength of boiler shells depends only on their resistance to circumferential tension, it was natural to infer, from an argument proving that in certain cases the circumferential tension is only a certain fraction of that formerly assumed, that in those cases the thickness of shell plate might be reduced in proportion to the diminished tension. The writer's experiments have proved the error of this inference which he had formerly drawn. He is now convinced that none of his models yielded primarily to circumferential tension, but to other strains not hitherto reckoned on, and in ways which he did not anticipate and cannot now calculate. Whether this is so or not, there are some reasons for thinking that pressure within a boiler tends to stretch the end plates as well as the shell; and there are good reasons for suspecting that the contrary assumption is not true, or at least not the whole truth. He therefore proposes to trace the consequences of the first assumption as far as he can.

To simplify matters, suppose a cylinder of uniform strength throughout, without any joints, the end plates being of the same thickness as the shell plates. Ignoring the staying of end plates, and confining our attention to strains derived from the shell plate, let the cylinder be, say, 20 inches long × 20 inches diameter, subject to a pressure of 100 lbs. to the inch. Let it be further assumed that the thickness of the shell plate is sufficient to transmit any strains that may come upon it.

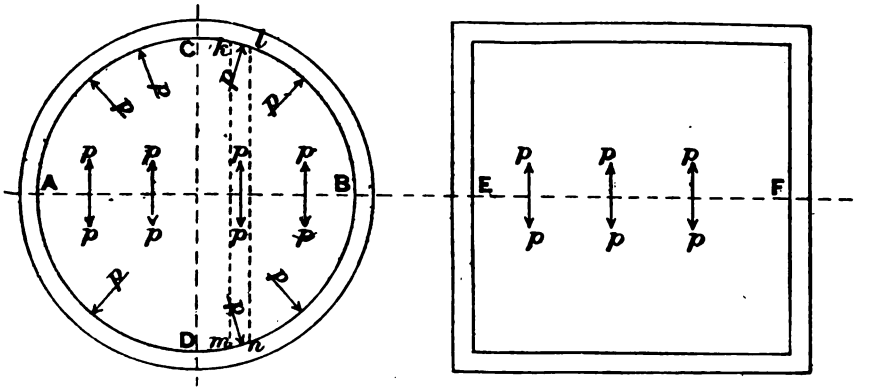
Of course, it cannot be questioned that a uniform circumferential tension throughout the shell plate—

= radius × pressure = 10 inches × 100 lbs. = 1,000 lbs.,

would exactly balance this pressure; but an essential condition of this solution is that the shell plate must be free to stretch uniformly throughout its length, which it is not, so long as the ends offer any resistance.

If A C B D (Fig. 8) is the end plate of this cylinder, any pressure transmitted to it from the shell will be uniform all round the circumference,

FIG. 8.



if this pressure is p lbs. per inch acting radially, and if *klmn* is a vertical strip in this plate, the vertical component of the radial pressures on the curves *kl* and *mn* will produce a tension = p lb. per inch, tending to stretch the strip in the direction of its length; and in the same way the pressure on A C B and on B D A will produce a uniform tension = p lbs. per inch, tending to split the plate through A B, or to stretch the plate in the vertical direction. This is, of course, true for all other diameters.

Again if A B C D (Fig. 7) is a square, the strain on the bolts in the flange A B will be the same as the strain on the bolts in the flange B C.

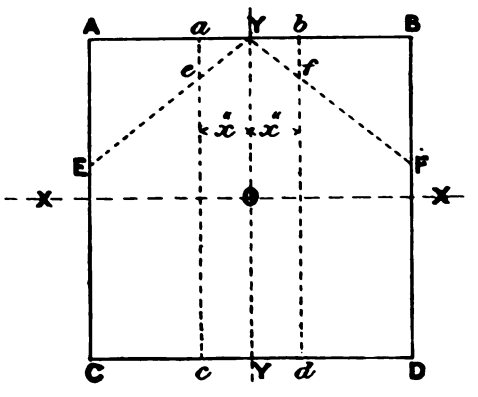
In the same way, as E F = A B (Fig. 8) the section through the cylinder is a square, the strain on the plate E F will be the same in amount and distribution as the strain on the plate A B. It has been proved that the strain on A B is a uniform tension = p lb. per inch, therefore the strain on E F is also a uniform tension = p lb. per inch. The pressure tending to rupture cylinder, through A B and E F = 20″ × 20″ × 100 lbs. = 40,000. If this is resisted by a uniform tension = p lb. per inch in the two sections of shell plate, and the sections of the two end plates, then—

$$p \times 2(20'' + 20'') = 40{,}000 \text{ lbs., or } p = \frac{40{,}000}{80} = 500 \text{ lbs.}$$

As all the central sections of a cylinder are alike, it may be said that, under the assumed conditions, 100 lbs. pressure within the cylinder will be balanced by a uniform circumferential tension in the shell plate of 500 lbs. per inch of length, and a uniform shearing strain of 500 lbs. per inch of circumference at the junction of shell with ends.

Now, a circumferential tension of 500 lbs. per inch will exactly balance a pressure of 50 lbs. on the shell, because 50 lbs. × radius = 50 lbs. × 10 inches = 500 lbs. The problem may therefore be divided into two parts. The shell, considered as an endless ring, sustains a pressure of 50 lbs. to the inch, and considered as a beam supported at the two ends, it also sustains a pressure of 50 lbs. to the inch. The first part presents no difficulty; the second part is not so simple, but still some steps towards its solution can be taken.

FIG. 9.



In the first place it is evident that in this beam the bending moment in any direction, say vertically upwards, due to pressure on the top half, is exactly balanced by an equal and opposite moment due to the pressure on the bottom half, and that all bending moments cancel each other. The next point to be considered is the distribution of shearing strains throughout the beam:—

A B C D is the outline of the beam, X O X being the axis of the cylinder, Y O Y being the centre of the length, *abca* is a ring $2x$ inches wide at centre of beam.

If a pressure of 50 lbs. per inch on this ring is transmitted to the two ends it must produce a strain = 50 × x on each inch of the circumference of the two circles *ac* and *bd*. This pressure acts radially and tends to shear through the plate all round the circumference, and is resisted by the resistance to shearing of the plate. The shearing stress at the point A will be 50 lbs. × A Y = 50 lbs. × 10 inches = 500 lbs. per inch of circumference. If A E = 500 lbs. on any scale, the line E Y, (Fig. 9) will give the shearing stress at any point; thus at the point (a) the stress will be given by the length of the line *ae*.

Thus if any pressure is transmitted to the ends of the beam, it will be transmitted as a shearing stress increasing uniformly from 0 at the centre to a maximum value at the ends. The same result would be obtained if we had commenced by assuming that the ends offered a resistance = 500 lbs. per inch, or it might be stated as a particular case of the general law of shearing strains in beams uniformly loaded.

The conclusion arrived at is, that a pressure of 100 lbs. per square inch in this cylinder will produce a uniform circumferential tension in shell = 500 lbs. per inch of length, and a shearing strain on the shell varying from 0 at the centre to 500 lbs. per inch of circumference at the two ends. The result of these strains on the cylinder is the next thing to consider.

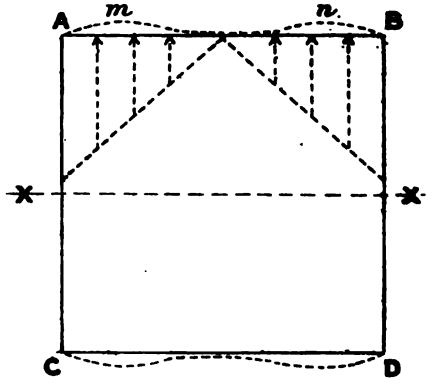
Suppose a tension of 500 lbs. per inch would stretch the shell plate $\frac{1}{n}$th part of its length, this would correspond to a uniform increase in diameter of shell = $\frac{1}{n}$th part of diameter. And, as previously stated, a stress of 500 lbs. per inch applied to the circumference of the end plates would produce a tension of 500 lbs. per inch in every diameter of the end plate, as the end plate is assumed to be the same strength as shell plate, this tension would stretch the end plate $\frac{1}{n}$th part of its diameter, and consequently, as both shell and ends would be increased by the same amounts, the cylinder would remain a parallel cylinder, $\frac{1}{n}$th part greater in diameter than before pressure was put on.

Up till now, it has been assumed that the pressure is such that any strain produced by it will not exceed the elastic limit of the resistance of the shell to that strain. But if the pressure is increased beyond this limit it will be seen that the distribution of strain will no longer continue as above. If there are any weak points in any structure, say a line of rivet holes in a boiler plate, the strain which would normally be distributed along the whole line is concentrated on the metal left between the holes.

And in the same way if pressure within a cylinder is resisted both by the resistance to shearing and the resistance to tension of shell plate. If one of these resistances fails to sustain its normal share of the pressure, then the other will have to sustain more than its share.

Thus if A B C D (Fig. 10) is an outline of the cylinder, X X being the axis, the normal distribution of strain brings one-half of the total pressure on the two ends and the other half on the ring as tension. If, now, it were possible to shear through the connection between shell and end plates, without allowing the pressure to escape, then the whole of the pressure would come at once on the ring, and the pressure which was formerly producing shearing strain would then produce circumferential tension. Or, again, the pressure acting on A B might find it easier to bulge the cylinder at some distance from the ends than to shear through it at the ends. If the shearing stress at *m* and *n* were greater than the elastic limit of the resistance to shearing at these points, then they would begin to bulge rapidly, but they could not bulge without increasing the diameter of cylinder, and this would be resisted by the circumferential strength of plates, and as the resistance of the ends decreased the strain on shell as a ring would increase. If the pressure could be increased after the shell began to bulge near the ends the decreasing support from the ends and the increasing strain on the ring would cause the crest of these bulges to travel towards the centre, and give the barrel form which was assumed by Model No. 3.

FIG. 10.



In this connection it is instructive to notice that in Mr. Scott's experimental boiler the form shown in Fig. 6 may be observed getting gradually more pronounced as the pressure rises to 580 lbs., where the structure was evidently strained up to or beyond its elastic limit, and that the next increment of pressure destroyed this form by greatly increasing the bulge on centre course, a result probably due to the fact that the end courses were unable to transmit any more pressure to the ends, and therefore the additional pressure only increased the circumferential tension.

Such a distribution of strain is consistent with all the results of these experiments. If the circumferential tension is much less than that ordinarily assumed, it can be easily seen how all these models stood a much greater pressure than can be accounted for on that assumption. It accounts for the form taken by Models Nos. 1 and 2. And if in No. 3 the plate had begun to yield in a similar manner at an equal distance from its ends, as in the longer models, it can be easily understood that as the distance between these points would be very small the additional strain brought on the short ring between these two humps, by the ends failing to transmit their proportion to the ends, would produce the barrel form that was produced. And, as in this case the pressure was applied very quickly, and the space for leakage was very small, it was possible to follow up the yielding ends until the joint at the centre burst, a result which could only be obtained where the supply of water was enormous in comparison with the size of vessel.

A strain of this character tending to increase the diameter of the ends more than the centre, if the resistance of the ends to increase of diameter was greater than the resistance of centre to contraction, might account for the contraction observed in Model No. 1.

If Nos. 1 and 2 were destroyed by a strain normal to the circumference this would account for the fact that the solid plates suffered as much as the weak joint, a fact not easily explained if circumferential tension were the strain that destroyed these models.

The only fact not explained by this hypothesis is that these models yielded near the end and not at the ends. If the reason why these plates failed to transmit more than a certain strain to the ends, and the limit of their resistance were known, the problem would be solved.

In conclusion, the writer considers he is justified in assuming that in any boiler working, as all boilers ought to work, at a pressure much below its elastic limit, the pressure is not balanced solely by circumferential tension in the shell plate, but is uniformly distributed over any central section through shell and ends. That this distribution of strain will continue until, as in these models, the elastic limit of resistance to shearing has been exceeded. After which, the proportion of pressure balanced by circumferential tension will be increased; but it can never be the sole resistance until the connection between shell and ends has been entirely destroyed.

TABLE No. VIII. MODEL No. 1.—26 INCHES DIAMETER, 44 INCHES LONG.

Pressure per sq. in.	Water pressure =		Extension of Joint at the Points marked in Fig. 1.					Extension of Plate at the Circles marked in Fig. 1.					Remarks.
			No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	
			In.	In.	In.	In.	In.	Steel tape 6 ft. $7\frac{5}{32}$ in. used for all circles.					
			$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$						
								In.	In.	In.	In.	In.	
					$-\frac{1}{64}$	0	0	0	0	0	0	0	Pressure applied by a small hand pump up to 630 lbs.
					0		0	0	0	0	0	0	
					$-\frac{1}{64}$	0	0	0	0	$\frac{1}{32}$	0	0	Joint commenced to weep at 200 lbs. at line 4.
					0	0	0	0	0	0	0	0	
				$-\frac{1}{64}$	$-\frac{1}{64}$	0	0	0	0	$\frac{1}{32}$	0	0	Weeping at same place, but no increase.
			0	0	$-\frac{1}{64}$	0	0	0	0	0	0	0	
			0	$-\frac{1}{64}$	0	0	0	0	0	$\frac{1}{32}$	0	0	Do., do., also at 1 rivet in bottom flange.
			0	$-\frac{1}{64}$	$\frac{1}{64}$	0	0	0	0	$\frac{1}{32}$	0	$\frac{1}{32}$	Do., do., do.
			0	$-\frac{1}{64}$	$\frac{1}{64}$	0	0	0	0	$\frac{1}{32}$	0	$\frac{1}{32}$	Weeping at same place, but no increase, also at 1 rivet in bottom flange; battens tried on cylinder, which was found to be quite straight.
470	Do.	on	$\frac{1}{64}$	$-\frac{1}{64}$	$\frac{1}{64}$	0	0	0	0	$\frac{1}{32}$	0	$\frac{1}{32}$	Leaking at several points in longitudinal joint and several rivets in flanges.
	Do.	off											
500	Do.	on	$\frac{1}{64}$	$-\frac{1}{64}$	$\frac{2}{64}$	0	0	0	0	$\frac{3}{64}$	0	$\frac{1}{32}$	Leakage increasing.
	Do.	off											
550	Do.	on	$\frac{1}{64}$	$-\frac{1}{64}$	$\frac{2}{64}$	$\frac{1}{64}$	0	0	0	$\frac{1}{16}$	0	$\frac{1}{16}$	Do., cylinder still straight by batten.
	Do.	off											
600	Do.	on	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{3}{64}$	$\frac{3}{64}$	0	0	0	$\frac{1}{16}$	0	$\frac{1}{16}$	Leaking heavily.
	Do.	off	0	0	$\frac{1}{64}$	$\frac{1}{64}$	0	0	0	0	0	0	
630	Do.	on	0	...	$\frac{2}{64}$	...	$\frac{4}{64}$	0	...	$\frac{1}{16}$	...	$\frac{1}{16}$	Leakage from joint was greater than hand pump could overcome; form of model unaltered.
	Do.	off	0	0	$\frac{2}{64}$	$\frac{2}{64}$	$-\frac{1}{64}$						
	Model was caulked all over and connected to the hydraulic service pipes in boiler shop.												
730	Do.	on	Measurements could not be taken on account of leakage.					...	...	...	...	...	Model bulged near the ends at 730 lbs. Pressure was maintained at that for a
	Do.	off	$\frac{5}{64}$	$\frac{6}{64}$	$\frac{9}{64}$	$\frac{5}{64}$	$\frac{1}{64}$	$1\frac{5}{64}$	$1\frac{13}{64}$	$1\frac{23}{64}$	$1\frac{21}{64}$	$1\frac{23}{64}$	but could not be increased.

TABLE No. IX.

Model No. 2. 26 Inches Diameter, 26 Inches Long.

Pressure per Square Inch in Model.		Extension of Joint at Points marked in Fig. 2.					Extension of Plate at Circles marked in Fig. 2.					Remarks.
		No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	
	Original length =	In. $3\frac{3}{4}$	In. $3\frac{3}{4}$	In. $3\frac{3}{4}$	In. $3\frac{3}{4}$	In. $3\frac{3}{4}$	Steel tape 6′ $7\frac{1}{16}$″ used for all circles.					Pressure applied by hand pump to 550 lbs.
Lbs. 300	With pressure on	0	0	0	0	0	In. 0	In. 0	In. $\frac{1}{64}$	In. 0	In. 0	Joint commencing to weep.
	Do. off	0	0	0	0	0	0	0	0	0	0	
400	Do. on	0	0	0	0	0	0	0	$\frac{1}{32}$	0	0	Joint leaking slightly.
	Do. off	0	0	0	0	0	0	0	0	0	0	
500	Do. on	0	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	0	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	Slight leakage from ends and longitudinal seams.
	Do. off	0	$\frac{1}{128}$	$\frac{1}{128}$	$\frac{1}{128}$	0	0	0	0	0	0	
550	Do. on	0	$\frac{3}{64}$	$\frac{5}{64}$	$\frac{7}{64}$	$\frac{1}{64}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{32}$	$\frac{1}{8}$	Leakage greatest near ends of longitudinal seams, hardly any at centre, cylinder straight by batten, and showing no visible alteration in form.
	Do. off	0	$\frac{2}{64}$	$\frac{4}{64}$	$\frac{4}{64}$	$\frac{1}{64}$	$\frac{1}{16}$	$\frac{1}{64}$	0	0	$\frac{1}{32}$	
	Pressure could not be increased by the hand pump. The model was caulked all over and connected to the hydraulic service pipes in boiler shop.											
450	...	Joint commenced to leak.										
550	...	Joint leaking all along joint.										
680	With pressure on	Could not be measured on account of leakage										At 680 lbs. model bulged out near the ends. This pressure was maintained for some time but could not be increased.
	Do. off	In. $\frac{1}{16}$	In. $\frac{3}{16}$	In. $\frac{3}{16}$	In. $\frac{5}{32}$	In. $\frac{1}{16}$	In. $1\frac{1}{8}$	In. $2\frac{3}{32}$	In. $1\frac{13}{16}$	In. $1\frac{15}{16}$	In. $1\frac{11}{32}$	

TABLE No. X.

MODEL No. 3. 26 INCHES DIAMETER, 13 INCHES LONG.

Pressure per Square Inch in Model.		Extension of Joint at Points marked in Fig. 3.			Extension of Plate at Circles marked in Fig. 3.			
		No. 1.	No. 2.	No. 3.	No. 1.	No. 2.	No. 3.	
	Original length =	In. $3\frac{3}{4}$	In. $3\frac{3}{4}$	In. $3\frac{3}{4}$	Steel tape 6′ $7\frac{1}{16}$″ used for all.			
Lbs. 150	With pressure on	0	0	0	In. 0	In. 0	In. 0	Pressure raised by hand pump to 550 lbs.
	Do. off	0	0	0	0	0	0	
300	Do. on	0	0	0	0	0	0	Commenced to leak in centre and near end.
	Do. off	0	0	0	0	0	0	Leak caulked.
400	Do. on	0	$\frac{3}{64}$	0	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	Joint leaking considerably. Caulked.
	Do. off	0	$\frac{1}{64}$	0	0	0	0	
500	Do. on	$\frac{1}{64}$	$\frac{4}{64}$	$\frac{1}{64}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{32}$	Commenced to leak, 350.
	Do. off	$\frac{1}{64}$	$\frac{4}{64}$	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	0	
550	Do. on	$\frac{3}{64}$	$\frac{6}{64}$	$\frac{1}{64}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{17}{64}$	Tried by batten. No alteration in form could be seen.
	Do. off	$\frac{1}{64}$	$\frac{5}{64}$	$\frac{1}{64}$	$\frac{1}{4}$	$\frac{17}{64}$	$\frac{5}{32}$	
	Pressure could not be increased by hand pump. Model was caulked all over and connected to hydraulic service pipe. The pressure from the accumulator was allowed to come on it at once.							
800	With pressure on	Joint	burst	...	...	...	..	Plate bulged and joint burst, tearing plate through at centre rivet holes.
	Do. off	...	1	...	...	$3\frac{5}{8}$	...	

TABLE XI.

TEST OF PLATES MADE BY THE STEEL CO. OF SCOTLAND AND USED IN MODELS.

Plate No.	Size of Sample			Size of Fracture.				Initial Strain.		Breaking Strain.		Extension Per Cent. on 8 Inches.	Shearing Strain.	Long or Cross.
	Breadth.	Thickness.	Area.	Breadth.	Thickness.	Area.	Per Cent.	Actual Tons.	Per Sq. In. Tons.	Actual Tons.	Per Sq. In. Tons.			
6,000	1·15	·18	·207	·95	·125	·1187	45	3·73	18·0	5·9	28·5	25	20·7	...
	„	·195	·224	·89	·14	·1246	44	4·1	18·3	6·45	28·7	20·5	20·5	+
6,001	„	·185	·213	·92	·105	·0966	54	3·8	17·8	5·95	27·9	24	20·32	...
	„	·19	·219	1·00	·15	·150	31	3·8	17·3	6·3	28·7	23	20·4	+
6,002	„	·17	·196	·94	·11	·1034	47	3·7	18·8	5·45	27·8	24·5	20·17	...
	...	·19	·219	·94	·145	·1363	37	4·1	18·7	6·2	28·3	20	20·27	+
							Average Value =		18·15	...	28·3	...	20·41	

A pressure of 322 lbs. per square inch on models would produce a strain of 18·15 tons per inch of plate in joints. On endless ring hypothesis.

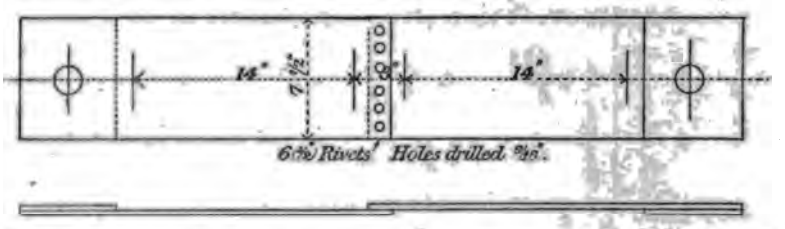
Do. 503 do. do. 28·3 do. Do.

Do. 586 do. do. 18·15 on plate Do.

Do. 915 do. do. 28·3 do. Do.

TABLE No. XII.

TEST OF JOINT.



Strain.	Corresponding Pressure on Endless Ring, 26 in. diameter.	Permanent Set.		
		Joint, 3 in.	Plate, 14 in.	
2 tons	Per sq. in. 46 lbs.	In. 0	0	Load was applied in 2 ton increments. Measurements were taken after the load had been applied and taken off. Plate and joint were measured from pop marks shown in sketch.
4 „	92 „	0	0	
6 „	138 „	0	0	
8 „	184 „	0	0	
10 „	230 „	$\frac{1}{128}$	0	
12 „	276 „	$\frac{1}{64}$	0	
14 „	322 „	$\frac{2}{64}$	0	
16 „	368 „	$\frac{3}{64}$	0	
18 „	414 „	$\frac{3}{64}$	0	
20 „	460 „	$\frac{3\frac{1}{2}}{64}$	0	
22 „	506 „	$\frac{5}{64}$	0	
24 „	552 „	Broke through joint	0	24 tons broke the joint and 22 tons did not break it; the exact breaking load would therefore be between 22 and 24 tons.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

SEVENTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON MONDAY EVENING, MARCH 9TH, 1891.

F. C. MARSHALL, ESQ., PAST-PRESIDENT, IN THE CHAIR.

IN the absence of the Secretary from indisposition, Mr. H. S. WALLACE, Assistant Librarian, read the minutes of the preceding General Meeting, held in Sunderland, on February 20th, which were approved by the members present, and signed by the Past-President.

The ballot for new members having been taken, the Past-President appointed Messrs. M. Sandison and J. C. Stirzaker to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Brown, James, Engineer, c/o Messrs. Martinez Rivas & Palmer, Astilleros del Nervion, Bilbao, Spain.

Evans, Charles, Engineer Draughtsman, c/o Messrs. Wigham Richardson & Co., Neptune Works, Walker-on-Tyne.

Greig, David William, Engineer Draughtsman, 31, Westmorland Road, Newcastle-on-Tyne.

Kendall, Stonard O., Ship Draughtsman, Messrs. Sir W. G. Armstrong, Mitchell, & Co., Walker; 17, Eversley Place, Heaton, Newcastle-on-Tyne.

Nicholson, James Day, Manager, Messrs. Mercantile Dry Dock Co., Jarrow-on-Tyne.

Stansfield, George R., Supt. Engineer, Aberdare Terrace, South Shields.

ADJOURNED DISCUSSION ON MR. A. BLECHYNDEN'S PAPER ON "THE INFLUENCE OF THE RELATIVE DIMENSIONS AND PROPORTIONS OF THE SCREW PROPELLER ON THE VESSEL'S PERFORMANCE."

Mr. B. G. NICHOL said that Mr. Weighton had thoroughly prepared himself to re-open this discussion, but his continued illness made that impossible. With that drawback, he rose with great pleasure to re-open the discussion on Mr. Blechynden's paper, on "The Influence of the Relative Dimensions and Proportions of the Screw Propeller on the Vessel's Performance," which had cost so much time, so much thought, so much labour, and had been so thoroughly well wrought out. He thought it would be of great value to the members of that Institution, and engineers and shipbuilders generally. In testing the evaporative power of any boiler they usually drew some datum line, though the feed-water might enter very much below 212 degs., and though the point of evaporation might be very much higher than that, over 400 degs. probably. They always, in estimating the efficiency of one steam generator as compared with another, brought the temperature to a common datum line. In this paper the same method seemed to have been adopted by the writer. There were a great many factors to be taken into consideration in an estimation of the efficiency of the screw, and Mr. Blechynden had evidently brought all propellers down to one datum line, a line suggested by the results of very great numbers of experiments which he carried out some time ago, and laid before them. The pitch ratio of his standard screw is $1\frac{1}{4}$ diameters, a very common ratio in their ocean-going steamers, and it appeared to him to be wise to bring all his experiments to the same ratio. In the same way surface area was dealt with. A very common proportion was about 38 per cent. of the disc area, and he also, it was to be observed, had adopted 38 per cent. surface ratio for his standard screw. Thus, from the variations which occurred during the experiments, he was enabled to evolve certain laws which would take account of different pitch ratios, different quantities of slip, and different amounts of surface area. Subsequently he (Mr. Nichol) noted, Mr. Blechynden had taken a very large number of steamers as near as possible conforming to those proportions for comparison, and to his mind, the agreement between these and the experimental results was really wonderful. After having done this, they had a further series which differed in speeds, pitches, and slips from the standard. These

had all been by the laws evolved in his experiments, compared with the normal propeller, and it was very gratifying to find the results approximating so closely as they did. They had in this series of tables one which gave them the value of the different pitch ratios and surface areas and always differing amounts of slip. It might here be noted that in the first table the apparent slip was different from that stated, but of course that took into account the wake factor of the steamer. He (Mr. Nichol) thought in order to make that paper perfect and useful in the hands of all engineers, some general comprehensive rule might be evolved from these tables which would embrace every case. They all knew that were all ships of one model, one design, all on the same lines, though different in size, and all to go at the same speed, it would be very easy to frame a rule to give the propeller of maximum efficiency in all cases; but the differences between their torpedo vessels, swift cruisers, Atlantic liners, and ordinary cargo vessels were so great that of course there was equally great diversity in the screws, and consequently great difficulty in finding a rule to cover every case. He thought from the comprehensive grasp of the subject which had been shown in the paper, that there could, with some little difficulty, perhaps, be evolved a comprehensive rule that might be of fairly general application, and as Mr. Blechynden would be amongst them that night he hoped he would have an opportunity of replying, and that he would be able to furnish them with such a rule as to be of general benefit. He (Mr. Nichol) thought they should all highly appreciate the efforts of Mr. Blechynden and set a high value on his paper.

Mr. DAVID MYLES agreed very much with what Mr. Nichol had just said about the value of this paper. He was only sorry that Mr. Nichol was so entirely laudatory. It would be much better if they tried to do something to improve the paper, or to call attention to some points about which they might have some doubts, with a view to having those doubts removed. On page 184 the author gave some particulars of propellers where bronze blades were substituted for steel blades, and stated that in the actual working those blades yielded to the pressure in such a way as to increase the pitch of the propeller. Well, he did not know that the author was altogether justified in assuming the apparent increase of pitch as being due to yielding of the bronze blades. He (Mr. Myles) supposed it was all an assumption; but, at any rate, as those bronze blades would be thinner, and have a finer surface than the steel ones, they would move more smoothly through the water, and disturb it less than the thicker cast steel blades, and thus leave the propeller a more solid body of water to work in, and that would have something to do with the increased

efficiency of the bronze blades. Again, he did not quite see how the blades would be expected to yield to the pressure in such a way as to increase the pitch of the propeller. He thought it must depend a good deal upon the distribution of surface relative to some centre line. He thought the surface of the blades might be disposed in such a way that instead of increasing the pitch of the propeller it would diminish it, and he (Mr. Myles) had heard of a case where that really took place; the blades were rather thin and yielded, the engine started to run away faster, and the ship really went slower. Then, on page 186, the author spoke about the average percentage of slip as varying from about 20 per cent. up to as high as 35 per cent. That seemed a very high percentage of slip; it might be right, but it seemed to him very high. He knew of some propellers made in which the average percentage ran about 5 to 7 per cent., but the $\frac{D^4\ V^3}{I.H.P.}$ coefficient was very low in these boats, and it might have been that the slip was below that required for the maximum efficiency of the propeller. He would like if some other speakers would give their opinion on that point. On page 190 the author gave a table of the saving that would result from a properly proportioned propeller. Of course there would be a saving on a properly proportioned propeller, but he thought that the saving claimed by the author was too good to be true. He was not in a position to check it, but it seemed rather bigger than one could really get. He quite agreed with anything anyone could say as to the value of this paper, and hoped the result would be that some one would be able to frame a formulæ something on the lines indicated by Mr. Nichol.

REPLY TO DISCUSSION ON PAPER ON SCREW PROPELLER.

Mr. BLECHYNDEN, who had not been present at the discussion of his paper that night, and had unfortunately mislaid the proofs of the remarks made by the two speakers at the previous meeting, said he felt considerable difficulty in replying to what he had not had the pleasure of hearing, but that he would endeavour to do his best, and proceeded to reply.

(The proofs of the remarks made by the various speakers on Mr. Blechynden's paper having been handed to him, Mr. Blechynden has thought fit to re-write his reply, and the following communication has been received from him.—EDITOR.

few members of the Institution who are not fully acquainted with the tow-rope literature, and probably few who will not also recognise that Dr. William Froude never gave utterance to that with which he seems credited in the sentence, "Mr. Froude had enumerated," etc. The speaker is equally unfortunate in his grasp of the subject in attempting to illustrate the "methods," and has mistaken the speed of the ship for the speed of the screw's advance, with the result that he finishes up with a screw about 4¼ feet too large in diameter. Let us try again:—

Indicated horse-power	800.
Speed of ship	9 knots.
K for 35 per cent. total slip, and 1·25 pitch ratio	350.
Visible slip, say	15 per cent.
And screw's advance (A)	10·6 knots.

Then

$$\text{Diameter} = \sqrt{\frac{K \times \text{I.H.P.}}{A^3}} = \sqrt{\frac{350 \times 800}{10{\cdot}6^3}} = 15{\cdot}3.$$

The question asked anent Fig. 4, Plate XXII., will be found fully answered on page 183, where reference is made to that diagram, but doubtless it must be given somewhat more attention than the speaker seems to have given other parts of the paper. His tabulated results of performances given seem highly creditable and ought to be a source of great satisfaction to owners and builders.

The wakes given in Table IV. are not, as Mr. Hök supposes, calculated from the performances of the model screws. In such a case the table would simply show that A was equal to B, because B had been made equal to A. The wakes were determined from the model trials of the vessels. The vessel A for example is the "City of Rome," the particulars of the screw are taken from the recorded measurements in the makers' works; the figures in the first three columns under trial are from the vessel's progressive series; the wake was determined by the late Dr. Froude when he made experiments with the model; the total slip as fraction of A is found by dividing the sum of the speeds of wake and apparent slip by A; K is taken from the diagram (Fig. 1, Plate XX.) for the pitch ratio 1·392 and the slip ·338; B is unity, because the blade was equivalent to the standard type; C is such a modulus as would be expected from the type of engine and its mean pressures, and is the most unsatisfactory factor of all, because there were no diagrams taken at a sufficiently low speed to accurately determine the engine's friction; the calculated horse-power is that estimated as necessarily indicated on the engine to work the screw with its known speed and slip; and the actual horse-power was what was determined by diagrams taken from the engine. When working under

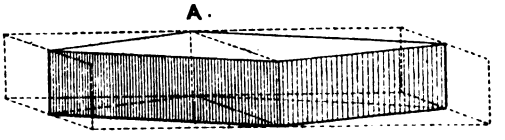
these conditions the screw was constrained to move with the ascertained speeds of advance and slip by virtue of its attachment to the ship whose resistances, direct and collateral, it had to overcome in doing so. What the relative or actual values of these individual resistances were it is not necessary to know for the purposes of the table, as the power necessary to overcome them and the engine's friction is known.

I fully agree with Mr. Hök that no treatise on screw propulsion can be considered complete without a full discussion of the details of the screw's influence in augmenting the net resistance of the vessel, the return of power by the wake, etc.; but doubtless he has realised, like most practical men, that in everyday work simplicity is a virtue, and until we know much more about the subject I prefer the simple method of determining the proportions of maximum efficiency indicated in the paper and illustrated in Fig. 6, Plate XXIII.

Mr. Hök's attempt at generalisation is most interesting, but it still requires something more. The proportions of the vessel have a good deal to do with the best ratio of disc as well as $\frac{S}{\sqrt{L}}$. The vessels whose results are plotted for speeds of $\cdot 75\sqrt{L}$; $\cdot 85\sqrt{L}$ and $1\cdot 05\sqrt{L}$ may for this purpose be regarded as similar; not so, however, those of Table V., which are very full. For the finer vessels the simple relation, $\frac{\text{Disc area} \times V^3}{\text{I.H.P.}} = 300$ is the condition of maximum efficiency for all speeds, and for fuller vessels the constant is approximately inversely proportional to the coefficient of lines.

I shall be very pleased to furnish the further particulars of the vessels of Table V. (page 188).

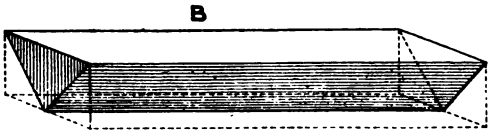
My reason for accepting the prismatic coefficient as the better guide to fineness will be best understood by an exaggerated example. Take two bodies, A and B, which we shall treat as ships, of which the block coefficient is in each case ·5.



Block coefficient, ·5; prismatic coefficient, ·5.

The prismatic coefficient indicates that A has fine water lines, and that B has square ends, while so far as the block coefficient is concerned they might both be alike.

I must thank my friend, Mr. Nichol, for his kindly remarks. I know of old his desire for a propeller formula, and the amount of labour he has expended in the endeavour to discover one. But I believe such a



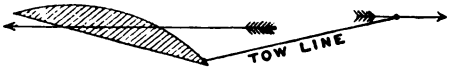
Block coefficient, ·5; prismatic coefficient, 1·0.

thing as he hopes for a practical impossibility, as each particular type of ship affects the question. The results of Fig. 1, Plate XX., are covered by a formula which has also wide application in practice, but without entering upon lengthy explanations it would be unwise to give it at the present.

Mr. Myles, while speaking of the bending of blades, very properly calls attention to the fact that the blade may be so formed as to have the pitch decreased in working. But such is not usual, and was not the case with those given as examples. I trust that the following may satisfy him that my conclusions on this matter are warranted:—

1.—The difference of the friction between bronze and steel or iron blades when the blades are smooth castings, and are painted, is practically *nil*, and cannot account for the difference. As usually made by good makers there is very little difference between the two classes of surfaces, even as they come from the foundry.

2.—The effect of a thick blade of the section generally adopted in propellers is to *increase* the working pitch over that given to the face of the blade, as Mr. Myles will find if he makes such a section and holds it or tows it by means of a string against a stream. The following sketch illustrates the direction it takes relatively to the stream:—



Arrows show direction of stream.

Thus the substitution of thinner blades should, so far as their mere thickness is concerned, tend to *decrease* the effective pitch and allow the screw to rotate *faster*, and not *slower* as was shown to be the case.

3.—A plate twisted like a propeller blade, when treated as a lever and loaded sufficiently to deflect, loses its twist, in other words increases in pitch. This has been tried and found so.

4.—Where bronze blades are made so weak as to take permanent set in working, it is found on measurement that the pitch is increased. A very marked case of this kind has recently come to my knowledge in a large Atlantic liner.

In his remarks on slip it would appear as if he had confused apparent with total slip. The 35 per cent. spoken of is the total slip and includes the wake, besides what is usually spoken of as the slip. For example take the vessel G, of Table IV., its total slip is 35 per cent., but its apparent slip is only $\frac{15{\cdot}08 - 13{\cdot}133}{15{\cdot}08} \times 100 = 19{\cdot}6$ per cent., and in the case of No. 10, Table VII. (page 191), whose total slip is 34·5 per cent., the apparent slip is only 14·5 per cent.

In regard to the saving estimated on page 190, by a better proportioned screw, Mr. Myles should observe that it is the saving as between Nos. 2 and 15, 16, and 17, and is consequently not overstated, but on the contrary, it could be shown that insufficient credit has been taken for the possible reduction of the weight of machinery due to the increased speed of revolution.

In conclusion, it is but right to state that this communication would not have been written had the means of making the experiments referred to not been furnished by my late enterprising employers, Messrs. R. & W. Hawthorn, through Mr. Marshall. I have also much pleasure in acknowledging the kind and willing assistance rendered me by Mr. James Andrews in checking many of the calculations in the paper.

PARTICULARS OF VESSELS OF TABLE V. REQUESTED BY MR. HÖK.

Reference No.	Moulded Draught.	Block Coefficient.
1	9·75	·401
2	18·125	·654
3	18·375	·705
4	17·5	·704
5	24·81	·651
6	19·06	·726
7	18·93	·731
8	21·5	·696
9	21·5	·696
10	23·125	·715
11	18·0	·686
12	22·16	·709
13	20·0	·650
14	22·5	·738
15	9·33	·657
16	22·625	·755
17	22·93	·698
18	20·18	·733
19	21·96	·660
20	10·4	·775

The PAST-PRESIDENT (Mr. F. C. Marshall) said he would now ask them to accord Mr. Blechynden their thanks for this very interesting and valuable paper. This was the second paper Mr. Blechynden had contributed on the subject of screw propellers, and he must say, that the literature on that subject, although already very extensive, had received a very great accession from the care and experience, and the experiments which their esteemed colleague, Mr. Blechynden, brought to bear upon it. He (the Past-President) had something to do with the original experiments which Mr. Blechynden undertook while with him, and he must say they were conducted with the greatest care and with very perfect accuracy, and he (the Past-President) knowing the tank arrangements in which the experiments were conducted, could not for one moment admit that there was anything in the arguments used that night as to the moving of the water by the propeller, instead of the moving of the propeller through the water, he could not see that that would in any sense vitiate the results arrived at. The results were all relative and what was good for one propeller was equally good for another, and the relations of the diameter to pitch were equally affected in one case as in another, and he believed those experiments were perfectly reliable data from which to work out a rule for propellers when they could arrive at it. Whether they had arrived at any satisfactory rule for the making of propellers was still an open question, he ventured to submit; but they were very much obliged to Mr. Blechynden for having pointed out the direction in which they must go, and for the results and valuable data he had brought together in this paper as the outcome of his experience. He need not tell them that that experience was very large, and therefore very valuable. They were very much obliged indeed for the trouble he had taken, for having contributed this paper to their Institution specially, and they valued his friendship and interest very highly. He was quite sure that anything Mr. Blechynden could do in the future to further elucidate and develop the subject he would do, and they might always rely upon it being of great value. He thought he ought further to say how much they were indebted to Mr. Blechynden for coming there from Barrow to speak to them. He tendered him their thanks for the labour he had bestowed on the subject.

The resolution was carried by acclamation.

MR. J. T. NICOLSON'S PAPER "ON THE STRENGTH OF SHORT FLAT-ENDED CYLINDRICAL BOILERS."

The PAST-PRESIDENT observed, in connection with the paper by Mr. John T. Nicolson, that if he might venture a remark, having just seen the paper, it seemed very scholarly and elaborate, perhaps requiring more of the class room element than was generally to be found in their meetings. Mr. Nicolson had evidently bestowed a great amount of attention to the subject. He was very well-known to some of them, having served his apprenticeship with him (the Past-President). Mr. Nicolson was now occupying a prominent position in Cambridge University, and he knew he only feebly expressed their sentiments in according to him their hearty thanks for his paper; and having met with their approval, that it should pass into the records of their proceedings. He begged to move that their best thanks be given to Mr. Nicolson for his paper.

This proposal was cordially accepted.

DISCUSSION ON MR. J. C. SPENCE'S PAPER ON THE "RESULTS OF EXPERIMENTS ON THE STRENGTH OF BOILERS."

The discussion on the paper on the above subject was opened by Mr. STIRZAKER. He said he thought none of them would doubt the value of Mr. Spence's experiments, or the accuracy with which he had recorded the results; but many of them would have great doubts as to the accuracy of the deductions which he drew from them. Mr. Spence claimed that his experiments proved the fallacy of their present method of calculating the strength of boilers or cylindrical shells. He (Mr. Stirzaker) thought they proved the correctness of that theory. Mr. Spence erred through trying to account for his facts by elaborate theories, instead of first seeking to reconcile them with our present knowledge and accepted laws; in short, he searched for truth at the bottom of a well, whilst all the time it lay upon the surface. For instance, he considered that "the most striking result in these experiments is the fact that the form finally assumed (in Nos. 1 and 2 boilers) was rather hollow in the centre. Uniform circumferential tension would, one would expect, produce a straight line, or one rather arched, like that of Fig. 3, Plate XXV., as the effect of ends would gradually diminish." He quite agreed with him. Mr. Spence called that

"the most striking result," and he searched, through all the recorded experiments which he could find, to discover a similar one. He thought he found it in Mr. Scott's boiler. Now, he (Mr. Stirzaker) considered that the real reason why Mr. Spence's shells expanded as they did, was to be found in Table XI., on page 235. The results of the test pieces were there recorded, which they found varied in thickness between 17-100ths and 19½-100ths, or nearly 12 per cent. It was well-known that some makers of plates would not guarantee to roll within 5 per cent. Surely that fact would account for the difference of expansion between one part of the plate and another. He (Mr. Spence) thought it must be due to the result of some general law. Well, perhaps so, but he (Mr. Stirzaker) thought it was the general law of plates being rolled rather finer at the edge than at the centre, and also of the metal at the ends of the plates where they were flanged not being quite homogeneous with the metal at the centre furthest from the flanging. He thought the difference in the homogeneity of the metal, and the difference of thickness, quite explained the fact of the boiler expanding more in one part than another. Mr. Spence pointed to Mr. Scott's boiler as a corroboration of his own experiments; but it was not. He thought Mr. Spence had got slightly wrong with his figures about Mr. Scott's boiler. The end which expanded very largely—52-64ths—did so because it contained the manhole. The centre of the boiler, and the other end of the boiler, expanded practically to the same extent as each other. If they would refer to Mr. Scott's paper, read before the Naval Architects (see Vol. XXX., page 291, Table XII.), they would find he there gave the expansion of the boiler, when under 580 lbs. pressure, not 18½-64ths and 34-64ths respectively, as Mr. Spence said, but 34-64ths and 32-64ths. This is almost parallel, and these boilers of Mr. Spence's were practically parallel. Dealing with No. 2 boiler, the difference of expansion between ring No. 2 and ring No. 3 was due to a very slight difference of stress, namely, about ·2 of a ton per square inch. He based that calculation upon the results of experiments published in Professor Unwin's *Test of Materials of Construction*. In that treatise, on page 280, Mr. Unwin gave a table showing the expansion of steel, which was of a similar nature to this, the elastic limit of which is put at 18 tons to the square inch. Working from that table, and taking the extension per unit of length of plate, he found that in No. 2 ring the extension was ·0265 inch per inch in length, equal to a stress of 19·8 tons per square inch, and at No. 3 ring the extension was ·023 inch per inch in length, equal to a stress of 19·6 tons, a difference of ·2 ton per square inch. Therefore he (Mr.

Stirzaker) thought they were justified in saying that the variation in the homogeneity and thickness of the plates quite accounted for Mr. Spence's "most striking phenomenon."

The second point Mr. Spence called attention to was the high pressure which the boiler carried, and he said that if the endless ring hypothesis were true a boiler could not have carried so great a pressure as this. But was this so? He had already shown the stress which actually came upon the shell was between 19·6 and 19·8 tons. Now, the stress as calculated by the ordinary formula for thin cylinders, when the pressure was 680 lbs. per square inch, is 21 tons; results slightly different, but sufficiently near to prove the correctness of his argument. He would like to emphasise the fact that the plate stood this stress in *circumferential* tension. Mr. Spence would say, "If that be so, how is it possible for the *joint* to have withstood that stress?" He accounted for that in this way—the joint was 55 per cent. of the solid plate, that would give an apparent stress upon each section of the plate between the rivets of 38 tons to the square inch, an amount which, of course, they did not for a moment suppose it would stand. But that was not the true, it was only the apparent, stress. The pitch of the rivets being $1\frac{1}{4}$ inches, the sectional area between each rivet was ·1289 square inch. Each of these sectional areas had the effect of the contraction of one of the rivets, the value of which was not by any means to be overlooked The friction created on the plates by the contraction of the rivets was very great. In a thick plated boiler it did not count for much, but when they dealt with a thin plate like those under consideration it told very largely. He calculated that the contractional stress or pull of the rivet was about 16 tons per square inch. The rivets were $\frac{9}{16}$ inch diameter, or $\frac{1}{4}$ of a square inch area, therefore the pull upon each rivet was about 4 tons. Now, if they assumed, as he thought they were justified in assuming, that the coefficient of friction was between ·2 and ·25, it would give them a friction of 1 ton per rivet. But the sectional area of the plate corresponding to each rivet is only ·1289 square inch, consequently, for a square inch of sectional area the value of the rivet would be $\frac{1}{\cdot 1289}$, or 7·75 tons. Therefore, the actual stress on the rivets was 38 tons, less $7\frac{3}{4}$ tons, which left $31\frac{1}{4}$ tons. The plates broke at 28 tons. The difference between 28 tons and $31\frac{1}{4}$ tons was not so great as to invalidate his method of reasoning. In conclusion, he thought he had shown that Mr. Spence's experiments were more valuable than that gentleman anticipated, inasmuch as they tended to establish rather than to disestablish present principles.

Mr. HECTOR MACCOLL (Belfast) said he had very great pleasure in being there that night. He had read, as far as he could read, the two papers on the strength of boilers. The first paper (Mr. Nicolson's), he would not for a moment pretend to discuss, it had been taken as above discussion by them, and it certainly was by him, but at the same time he could thank Mr. Nicolson for his very valuable and talented contribution to their literature on the subject. Now, engineers often heard this phrase—"That's all very fine in theory, but it's no good in practice." He held that nothing could be true in theory that was not correct in practice. On this occasion they had two papers got up quite independently, one having no connection with the other; yet one proved certain things mathematically, and the other proved them experimentally. He quite agreed with the last speaker (Mr. Stirzaker) that that was the precise value of Mr. Spence's experiments. He had proved quite conclusively that the ends of boilers had practically nothing to do with the strength of the plate in the middle of the shell. He had there diagrams of a number of joints (A to F, Plate XXVI.) which he had not brought before them with the idea that they had anything to learn therefrom, but to show ordinary proportions of joints and compare them with the proportions experimented upon. These diagrams showed thickness of plate, proportions of joint, and diameters of shell six times that used in Mr. Spence's experiment. His experiment was conducted on a shell 2 feet 2 inches diameter, with plates $\frac{3}{16}$ inch thick, and rivets $\frac{9}{16}$ inch diameter; multiplying that by six they got a shell of 13 feet diameter, plate $1\frac{1}{8}$ inches thick, and rivets $3\frac{3}{8}$ inches diameter. Fig. E represented Mr. Spence's experimental joint multiplied six times. He wished to call their attention particularly to that, because it showed conclusively, whatever the result of Mr. Spence's experiments might have been on the particular shell to which he applied them, that in one respect only could it be called a model shell. It was only a model shell in this respect and no other, that the thickness of plate bore an ordinary proportion to the diameter of the shell. The diameter of the rivet in proportion to the thickness of plate could not be called a model, because by the same rule they got a plate $1\frac{1}{8}$ inches thick, with rivets three times the thickness of the plate, or $3\frac{3}{8}$ inches diameter. Whatever results may have been got from the experiments, the proportions by which they were got could not be applied in ordinary practice. No one would think of riveting $1\frac{1}{8}$ inch plates with $3\frac{3}{8}$ inch rivets, nor did he think that existing machinery could deal with such enormous rivets. He quite agreed with Mr. Stirzaker as to the reason why this shell bore such an extraordinary pressure. He thought if they

looked at the lower section of Fig. E they would at once see that owing to the excessive diameter of the rivet and head, only a small part of the plate was free from its influence, and he was quite sure if they could have seen these experiments what they would have found would have been this, until the moment of rupture the stress was not coming through the section between the rivets, which with its double thickness was practically solid, until the moment the plate parted, they were therefore not dealing with 55 per cent., but with from 100 to 110 per cent. Hence the enormous pressure that was got. Then there was another great point put forward by Mr. Spence as the result of his experiment, the fact that all these cylinders did not bulge in the middle. In addition to the reasons given by the last speaker, which he thought very satisfactory as far as they went, there were, he thought other reasons that might be adduced. They would note that only one of these shells burst; but up to a pressure of about 550 lbs. all of them performed practically alike, which proved, he thought conclusively, that up to the point of rupture the plates were practically solid, solid rings with no joint in them, and consequently the expansion or bulging was very small, just as might have been expected. The cylinder, No. 3, on account of its small surface for leakage Mr. Spence was able to burst, and he suddenly got the shape shown in the diagram, and he had no doubt if Mr. Spence had been able to apply sufficient pumping power to Nos. 1 and 2 he would have got in them the same form. The differences might be accounted for in various ways, and it was just as well for them to consider every point they could think of. What he found was, that there were in all three cylinders what he would call constructional irregularities. Although these were considered duplicate in regard to diameter, thickness of plate, and riveting, they did not behave exactly alike. No 3 shell, which of the three should have been tightest, leaked most. Mr. Spence never got more than 550 lbs. pressure on that shell by the hand pump, whereas on No. 1 he actually got 630 lbs. Very well, that told them distinctly there must have been little differences in the manufacture of these three shells. If all three had been precisely alike in every respect, they were bound to believe that No. 3 would have stood more pressure by the hand pump than the others; instead of that it stood least of all. The joint was only one-third of the length of No. 1 and yet had more leakage than it, all of which pointed conclusively to the fact that there were irregularities which accounted for many of these things. Another point of which Mr. Spence had made a great deal, but which was not worth noticing, was what he called contraction of the joint under pressure. He was surprised

Mr. Spence had made so much of this, and could only account for it by the fact that Mr. Spence had a theory which he wished these experiments to prove. He was satisfied Mr. Spence conducted these experiments in the most conscientious way possible, and that he had in the most manly way given them the results, although they did not by any means corroborate his own theories on the subject. Really, this point appeared to him quite simple. The supposed contraction appeared only in No. 1 cylinder, in it only at two points, and at the lower pressures, disappearing at the higher pressures. Well, his explanation was that the joint at these particular points happened to be made flatter than it ought to have been, so that when pressure was applied the joint bent out into its proper form, and consequently the distance measured in a straight line over the joint by the compass points appeared shorter under pressure than when free. At the higher pressures the apparent contraction disappeared, and the plate at these points stretched, as might have been anticipated, similarly to other parts of the structure. Certain irregularities appeared in all such experiments, but these gradually disappeared the nearer the ultimate strength of material was approached. In Mr. Scott's experiments great irregularities appeared in a number of points at the lower pressures, and Mr. Spence had, rather unjustly, he thought, taken advantage of some of them in his Fig. 6, Plate XXV. The extraordinary bulging shown in the left hand ring of Mr. Scott's shell was obviously due to a weak manhole, and when the higher pressures were reached the middle ring bulged more than the right-hand one. That was the only point in which he would say Mr. Spence had not been quite fair to them. Mr. Spence's conclusion was that riveting should be arranged solely with a view to tightness and caulking, so long as the section of joint was not less than 55 per cent., and that any joint having 55 per cent. section might be taken as equal to solid plate. That was surely an enormous fabric to build on so slender a foundation as these three experiments. When Mr. Spence got out his specification for that edifice, he made bold to say he would not get a "strong" contractor to carry it out, and guarantee the result. There were other things to be considered in building boilers besides the first hydraulic test, and he thought he was right in saying that no engineer in this country would propose to make a boiler to work up to 160, 180, or 200 lbs. with single riveted joints in the shell. He knew no man of any experience, or with any regard for his reputation, who would turn out such a boiler with the expectation that at the end of ten years it would be a boiler at all. They knew it would not be a boiler. The joints in the shell of a steam boiler, require to

be fit for more than one test, and he had no hesitation in saying that no single riveted joint was capable of satisfactorily performing the work which had to be done by boilers of the dimensions and pressure now in use at sea. They required in riveted joints breadth, and a proper distribution of rivets, to give them the stability necessary for continuous and successful performance of their work, and this was only to be found in some of the forms of multi-riveted joints. For example, Fig. D, Plate XXVI., had the same rivet area as Fig. E, and the same plate area as Fig. F, and he had no hesitation in saying that it, or something like it, would secure a stronger, a tighter, and a more lasting shell than either Fig. E or Fig. F. Mr. Spence spoke of arranging a joint solely for tightness and for caulking. So far as he had seen, a joint whose tightness depended upon caulking was not a proper joint to be used in a boiler shell. He knew from experience that with plates $1\frac{5}{16}$ inches thick, a joint with 12 inches pitch could be made absolutely tight under 360 lbs. test pressure, and 180 lbs. continuous working pressure. Clearly that was a joint independent of caulking for tightness, and one not approved by the Board of Trade. An important point in this connection, and one to which this Institution might well devote some of that energy which it appeared to have in abundance, was the limiting by the Board of Trade of the pitch of rivets to $8\frac{1}{2}$ inches in boiler joints. To say the least of it, such limitation was neither in accordance with science nor with common-sense. If the limit was right for plates $\frac{1}{2}$ inch thick, it could not be right for plates $1\frac{1}{2}$ inches thick; and pressure ought to be brought on the Board of Trade to give a satisfactory reason for its rule, or to abandon it. While they were much indebted to Mr. Spence for his experiments, and while, no doubt, much remained to be learnt from future experiments, there was, as yet, no cause to fear, as Mr. Spence did, that any established principle had been unsettled.

COMMUNICATION FROM MR. WALLIKER.

March 7th, 1891.

DEAR SIR,—I regret that I shall not be present at the meeting on Monday night; but I should like to say a few words with regard to the paper read by Mr. J. C. Spence on the "Results of Experiments on the Strength of Boilers."

First, with regard to the sagging, may I suggest that this is due to

the contraction of the two long models when the stress was relieved? I believe that no observations were taken as to elongation, and a very slight degree of lengthening would account for this—the difference in diameters between end and middle being only about $\frac{1}{4}$ inch.

I think it is a matter for congratulation that the experiments have proved the efficiency of the lap joint, which I am glad to see is coming more and more into general use for boilers at high pressures. It is easy to close in the shop, and consequently easier to keep tight in ordinary work than the cumbersome double butt strap, and I anticipate that some day the handicap under which it labours will be abandoned.

It will be seen by looking at Tables VIII., IX., and X., pages 232, 233, and 234, that all the models commenced to leak at from 200 to 300 lbs.; and although this is a little higher than calculated, still it is below the elastic limit, and this has to be our guide in practice. Absolute tightness is a necessity in boiler work, and I do not think it would be possible to have a satisfactory test at much above the pressures now in use.

Through the courtesy of Mr. Spence I had an opportunity of testing a joint similar to the one used in the models, and made from strips cut from No. 1, and the result obtained was much higher than Mr. Spence's, as it gave a total of 34·35 tons per square inch, while the strips I tested were respectively 27·8 and 29·6 tons per square inch.* Using these higher figures, and also allowing for the plate to be slightly thicker than $\frac{3}{16}$ inch, viz., ·2, will give a much higher ultimate strength than is shown in the paper. I think that small models like these may be found to be misleading from their very size, and that until the tests are carried out on a larger scale that nothing definite should be deduced from them. We have got now a boiler shell which is standing well the practical everyday test of the

* TEST OF STRIPS AND JOINT CUT FROM MODEL NO. 1 AFTER EXPERIMENTS.
(Referred to in Mr. Walliker's Communication.)

No. of Test.	Dimensions.			Tons. Breaking.	Tons per Square Inch.	Per Cent. Ex.	Permanent Set.		Remarks.
	Breadth.	Thickness.	Area.				Tons.	Tons per Square Inch.	
Plate I. ...	1·35	·2	·270	7·5	27·8	20	4·4	16·3	
Plate II. ...	1·35	·2	·270	8	29·6	17	3·7	13·7	
Riveted joint	$3\frac{3}{4}$	...	...	...	...	...	...	...	
3 rivets, $\frac{11}{16}$ inch	$1\frac{13}{32}$	...	...	...	...	...	...	...	
	$2\frac{9}{32}$	·2	·431	14·9	34·6	...	7·1	16·5	

mercantile marine. It can be made tight and efficient; and if it errs, which I am not prepared to allow, on the side of strength, which also means longevity—why, so much the better for the shipowner.

I would add that Mr. Spence was most anxious that everything, in conducting these tests, should be made in a most thorough manner; and I think that the Institution is indebted to him, and also to Mr. Alex. Taylor, for their public spirit in carrying out such an interesting set of experiments as these have been.

I am,

Yours faithfully,

JOHN F. WALLIKER.

Mr. B. G. NICHOL said the whole of the experiments had been carried out by three of them quite independently of Mr. Spence, although in his presence. The observations were taken and recorded by Mr. Saunders, Mr. Walliker, and himself, and there were occasionally other gentlemen present. As to the measurements of the stretch of the joint and the circumference, he might say that these were accurately observed and recorded. Mr. MacColl's remarks had a very small bearing on the experiments, being practically a lecture on riveted joints. He (Mr. Nichol) did not think it advisable to use rivets of less than $\frac{1}{4}$ inch diameter for $\frac{3}{16}$ inch plates. Mr. Saunders, who was present, could corroborate him in stating that the cause of the joints holding, or rather failing to rupture, was not because of the friction between the plates caused by the riveting, as after leakage fairly commenced they inserted the blades of their pocket knives between the plates. He was convinced by the experiments that the end plates of boilers should be taken into account in determining the strength of shells, and that a substantial reduction in thickness may be made on present practice. In reply to Mr. Stirzaker's remarks, the plates were all cut from one large plate and not sent in by the steel makers with thin edges.

MR. SPENCE'S REPLY.

Mr. J. C. SPENCE, in reply to the discussion on his paper, said the fact that truth is seldom to be found on the surface, but generally lies hidden at the bottom of a well is so well-known that it has become proverbial. Mr. Stirzaker, however, appears to consider that truth can only be found on the surface, and his only criticism on the theory propounded in this paper is that it is not necessary to search diligently for a theory to agree with facts, the proper course being to try and reconcile the facts to the accepted theory. Now, if the accepted theory were

unquestionably true this might be the proper course, but considering that it is avowedly based on the omission of one factor assumed to be of no consequence, and that, by argument and experiment he had demonstrated that this factor is not small, but one of the principal, if not the chief factor in the problem, it can hardly be expected that he would try and reconcile the facts to a theory which he considered untenable. Mr. Stirzaker's attempts to effect this reconciliation are not very successful. He did not propose to follow all Mr. Stirzaker's ingenious arguments on the subject, but would deal with one or two crucial points which are capable of absolute proof.

The first and most important of these is the strength of the joints used in these models. In accordance with universal and well-grounded practice he had taken the strength of the joint as equal to the strength of plate section between rivet holes. Mr. Stirzaker, on the other hand, argues that the friction of the joint increases the strength to nearly double that of the plate section. In reply to this it might be considered sufficient to reiterate what Mr. Nichol had pointed out, namely, that at the higher pressures obtained in these experiments there was a stream of water rushing through the joint, and that a tester could be passed between the plates from rivet to rivet, a condition of things absolutely incompatible with the notion that friction of joint was an appreciable quantity.

The PAST-PRESIDENT—At what pressure did the leakage begin?

Mr. SPENCE—Such a leakage as that referred to did not occur till the pressure supposed to correspond with the ultimate strength of the joint had been passed. In No. 1 experiment there was about 20 per cent. more than the breaking strength of the joint before the leakage reached this extent.

The PAST PRESIDENT—You are rather defeating your own arguments, because if the ultimate strength was arrived at before the leakage commenced, the leakage did not affect the condition.

Mr. SPENCE—That is so. Still, the pressure rose much above this limit, and friction of the joint when most needed could not be in action. Thus, according to accepted theory, the breaking strength of the joint was reached at 500 lbs. pressure on the model. In the instance quoted, the joint did not open out till about 600 lbs. pressure was reached. Even if there had been friction of the joint up to this point, there could be none after it. How, then, is it possible to believe that friction enabled [illegible] pressure of 730 lbs.?

But why argue about what might be the strength of the joint when there is positive evidence of what the strength was? Table XII. (page 236) gives the actual strength of the joint. This test piece was made from plates cut from the same plates as the models were made of; the holes were drilled from the same template; the rivets were taken from the same bag, the width of specimen, 7½ inches, is sufficient to give reliable average results. Now, in Table XI. (page 235), there are the tests of the same plates, and from this it is seen that "initial strain" took place at from 17·3 to 18·8 tons per square inch. In Table XII. permanent set began to be visible at a strain of 10 tons, and was appreciable at 12 tons. The area of the section between rivets is ·8 inch nearly, which corresponds with a strain of 12½ to 15 tons to the square inch, that is to say, the elastic limit of the joint was rather below that of the solid plate. How then was it possible for friction to have caused the apparent increase of strength in the model when we find there is no such increase of strength in the test piece? The breaking strength of this joint, 24 tons, corresponds to a strain of 30 tons per square inch. This is somewhat above that of plate. This excess is due to causes which will be given after, but is clearly not due to friction of joint.

If further evidence of the real strength of this joint is required there are the tests of plate and joint given by Mr. Walliker. Here the elastic limit of the joint is given at 16·5 tons per square inch. In the model (No. 1) from which Mr. Walliker's test pieces were cut, the elastic limit of the joint was not reached till the pressure rose to 600 lbs. per inch, which corresponds to a strain of 33 tons per inch if the current theory is true. Is it credible that a joint which in the testing machine reaches its elastic limit at from 15 to 16½ tons strain should only reach the same limit at a strain of 33 tons per inch in a cylinder? Is it not more credible that the theory which assumes that it was subject to this strain is erroneous? He ventured to say that it was absolutely impossible that the joint could have been subject to the tensile strain calculated on the endless ring hypothesis. If so, it is not an open question, but an absolute certainty that the difference between the calculated strain and the real strain was transmitted to the ends; there is no other possible alternative. And again, it is not a debateable point but an absolute certainty, that if any of the pressure in the shell was transmitted to the ends, it must have been transmitted as a shearing strain increasing from the centre to the ends. Knowing, then, that a considerable pressure was transmitted to the ends, knowing also that the transmission of that pressure must have produced a shearing strain increasing from the centre towards the ends, he concluded that this

action was the cause of the bulge in the cylinder increasing from the centre towards the ends. Compare the strength of this argument with the hypothesis offered by Mr. Stirzaker as a solution of the question: he suggests that plates in the process of rolling are likely to be thicker at the centre than at the ends, and therefore the extension at the ends should be greater than at the centre. To this suggestion he would reply, in the first place, Mr. Stirzaker has given no proof that plates are appreciably thicker at the centre than at the edges. In the second place, even if this is so, as No. 2 model was cut from one side of a plate 4 feet wide, the centre of this plate would not correspond with the centre of the model but with one end of it, that is to say, the thickest part of plate stretched more than the thinner part by his hypothesis. In the third place, after the experiments were concluded several test strips were cut from No. 1 at different distances from the centre; four of these strips, taken from different places, were gauged, and found to be the same thickness. (See Mr. Walliker's tests, page 256.) There is one other point referred to by Mr. Stirzaker, namely, the results of Mr. Scott's experiments, on which he wished to say a few words. Mr. Stirzaker says that "he" (the speaker) "had sought through all the records of former experiments to find a similar one, and thought he found it in Mr. Scott's boiler." Now, this is very nearly the fact, but he would ask them to take the statement as he had given it at top and bottom of page 222. Mr. Stirzaker says with reference to Fig. 6, Plate VII., that the end which stretched most did so, because it contained the manhole door, but the manhole door was on the top, and the measurements here given were taken at the sides, that is, at right angles to the door. Judging from his own experiments the effect of a weak spot is very local (see Figs. 4 and 5, Plate VII.), and besides that, the manhole was strengthened by such an unusually strong compensating plate, that it is doubtful if it were a weak point, although it was, of course, a cause of leakage. Mr. Stirzaker also says that at 580 lbs. the centre course stretched to about the same size at the ends. Well, he had already said the same thing (see page 230), and he would also say that in models No. 1 and No. 2, if leakage could have been stopped and the pressure increased, the bulges at the ends would have quickly increased and spread towards the centre, and would have given a form like No. 3.

Mr. Scott's experiments are, or ought to be, in the hands of every one who wishes to make a serious study of the strength of boilers, and he would only ask those interested to compare his statement (page 230) of the behaviour of this experimental boiler with the facts.

Mr. MacColl commences his criticism by the statement that true theory and correct practice are inseparable. This no one will dispute, but unfortunately it does not afford the slightest help in deciding what is the true theory, or what is the right interpretation of certain experiments. Until recently he thought that practically the whole of the pressure on a boiler was balanced by circumferential tension in the shell plate; but an investigation of another question drew his attention to the enormous load which could be carried by a beam of the proportions usual in marine boilers, and convinced him that this theory was incorrect. Starting from axioms which are indisputable, he found that the circumferential tension on shell plates is always less than that hitherto assumed, and that it is very much less in short than in long boilers. As he had not entirely freed himself from the idea that the strength of boilers depends solely on circumferential tension he concluded, that short boilers would stand greater pressure than long ones. Experiments made with a view to test this, pointed to an opposite conclusion, at the same time they proved that the circumferential tension was only about one-half of that usually assumed. Further investigation showed, that any part of the pressure on a boiler which is not converted into circumferential tension must be transmitted to the ends as shearing stress. And therefore, where the proportion of pressure converted into tension is least the proportion transmitted as shearing stress will be greatest. As the resistance of steel plate to shearing is much less than its resistance to tension (see Table XI.) it is not surprising to find that the weakest model was not the one in which the tension was least, but that in which the proportion of shearing was greatest. Not knowing how the resistance to shearing in a cylinder is related to length, to diameter, or to both, he could not call his theory a complete one, but he could say that the whole of the investigation was based on the necessity of having theory and practice in perfect harmony.

Mr. MacColl says that Mr. Nicolson's paper proves mathematically that the accepted theory is true, but he admits that he has not studied the paper. Had he done so, he would have found that it does not prove, and does not attempt to prove, the question in dispute. It assumes it to be true, and from that assumption deduced certain numerical results. The question in dispute was stated by him (in his former paper on this subject) in language as plain as he could make it, so plain that he could not understand how any one, at least any engineer, could fail to understand it. It is this, in calculating the pressure which can be transmitted to the ends of a boiler by a longitudinal strip of the shell plate, is this strip to be treated as if it were an independent beam supported solely at the ends, with its neutral axis in the centre of its thickness; or is it to be

treated as forming an integral part of a large beam with its neutral axis at the centre of the boiler, and with bending moments balanced in all directions? If the first of these methods is right, then he admits the accepted theory is practically true. If the second, then it is most certainly wrong. Surely the alternative hypotheses are plain enough, and the second one is not so palpably absurd as to be dismissed without consideration.

Yet Mr. Nicolson without one word of comment or argument calculates the strength of a longitudinal strip on the first of these assumptions as though it never had been disputed. In doing so he neglects a resistance, which in the language of mathematicians becomes "infinite" in the case that he is investigating. If $a\ b$ (Fig. A) is a section through a longitudinal strip in a boiler, before this strip can act as an independent beam it will have to shear through the plate at a and at b. If the resistance of the plate to shearing is S, the resultant of the resistances at a and b is $2\ S \cos \theta$. The pressure on the strip being $P \times 2\ R \sin \theta$. R being the radius of the boiler and P its pressure. The ratio between resistance and pressure therefore varies as $\frac{2\ S \cos \theta}{2\ RP \sin \theta} = \frac{S}{PR} \cot \theta$. Now, $\cot \theta$ becomes indefinitely great as θ becomes indefinitely small, and is infinite when θ is nothing, which is the case investigated by Mr. Nicolson. It is quite true that cot θ becomes nothing when the angle θ is 90 degs. θ, that is when $a\ b$ is a semicircle, but in that case, the depth of the beam is not the thickness of the plate, but the radius of the circle. And a beam whose depth is the radius of a boiler would probably be several thousand times as strong as one whose depth is the thickness of shell plate.

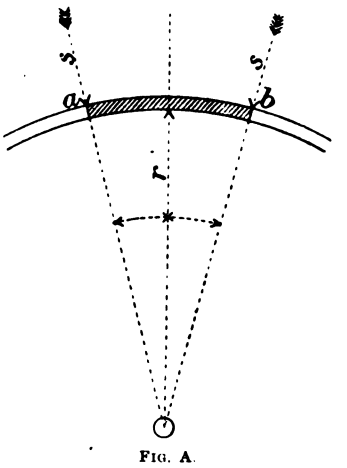


FIG. A.

After endorsing a paper which he had not studied, Mr. MacColl brings forward some perfectly sound arguments of his own to prove that the proportion of rivets used in these experiments is not suitable for ordinary boiler work. He (Mr. Spence) had not foreseen the possibility of anyone understanding the word "model" in the sense that these experimental cylinders were models or examples to be copied in every detail, or he would have stated explicitly, what he had implied in several places, that the proportion of riveting used in these experiments is not intended as a model for boiler makers to take as their standard. He now begged to

explain, for Mr. MacColl's benefit, that the models were designed solely to ascertain the amount and distribution of strain in a boiler, and had no reference whatever to the best form of joint. As Mr. MacColl had proved that the style of riveting suitable for $\frac{3}{16}$ inch plates was not suitable for $1\frac{1}{8}$ inch, he must admit that the proportions of joints suitable for $1\frac{1}{8}$ inch plates would not have been suitable for $\frac{3}{16}$ inch plates. Having some doubts as to what plan of riveting to adopt he had consulted their foreman boiler maker (Mr. Singleton), and having asked his advice, he had followed it. This may not appear a very scientific method of designing a joint, but for his part, he considered the opinion of an experienced practical man on a practical point of far more value than what passes for scientific method, and which generally means second-hand knowledge taken from books, instead of first-hand knowledge derived from facts. As a matter of fact, the joints used in these models were perfectly suitable for their purpose, but were not intended as a model for other purposes.

Mr. MacColl states, and severely criticises, as a conclusion of his (Mr. Spence's), "That any joint having 55 per cent. section might be taken as equal to solid plate." As such a conclusion is not only absurd on the face of it, but inconsistent with the whole of his argument, he would ask them to read the conclusions as given by him (page 230), and they would see that the conclusion arrived at was not, that joints of 55 per cent. section were as strong as the solid plate, but that, owing to the support received from the ends, a joint of only 55 per cent. section was enabled to carry a greater pressure than the solid plate could have carried, according to the erroneous theory in general use. And again, instead of suggesting that boiler joints should be reduced to 55 per cent. section, his argument was, that if these models, with these excessively weak joints, stood the pressure which (according to current ideas) corresponds with the strength of solid plate, then the stronger joints usual and proper in boiler work will certainly stand a pressure estimated in the same way. They might stand more—all he argued was that they would not stand less.

Replying to Mr. Walliker, he said that he failed to see how contraction of the models after the stress was relieved could account for the peculiar form taken by them. Assuming that pressure stretched them longitudinally, he could understand that when the pressure was released they might return to their original shape, or they might curve outwards or inwards, but that this contraction should produce first outward curvature near the ends and then inward curvature towards the centre, seemed to him impossible. Mr. Walliker's suggestion that the elastic limit of a joint is reached whenever it commences to leak is a strange one. He believed there were very few boilers tested to 300 lbs. for the first time

in which joints and rivets did not commence to leak, and yet it is known that this pressure is very much below their elastic limit. If, instead of starting a new fancy definition for the elastic limit of a joint, he would compare the elongations of joint given in Table XII. (page 236), with the elongations of joints given in Tables VIII.-X. (pages 232–234), he would see that the elastic limit was not reached till the pressure was from 500 lbs. to 600 lbs., or about twice the pressure corresponding to elastic limit on old theory. The next point raised by Mr. Walliker is a very interesting one. On testing strips cut from model they were found to break at 27·8 tons and 29·6 tons per inch; but a joint made of strips cut from alongside of these ruptured at a strain of 34·6 tons per square inch. This, at first sight, seems to give some colour to the contention that friction of joint has a real existence; but that is entirely negatived by the fact that the elastic limit of joint corresponds closely with that of uncut plate, showing that the friction at that point was so small as not to affect the strength; and if the friction is too small to be appreciable at the elastic limit, it will be less at the breaking point. He was indebted to Mr. Sanders for a suggestion which appeared to him to be a perfect solution of this apparent anomaly. Fig. B represents a joint to be tested. It will retain this form until the strain is sufficient to produce considerable movement in the structure, that is until the elastic limit is passed, but before rupture takes place, these thin pliable plates will take the form shown in Fig. C. With the two plates in the line of strain,

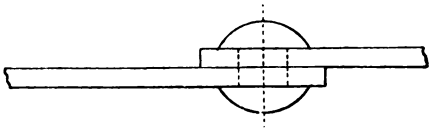


FIG. B.

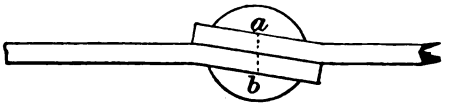


FIG. C.

and the joint canted over to a considerable angle, in this position the resistance of the joint will not be measured by the thickness of the plates measured at right angles to the plate, but by a longer line square to the line of stress, but diagonal to the plate. See *a b*, Fig. C. On reference to the fractured specimen it was found that this was exactly what had happened. Fig. C. is in fact scaled from the fractured joint, and the fracture is not square to the plate, but inclined at a considerable angle, the area of fracture being therefore greater than that assumed accounts for the apparent strength of joint. Now this action did not take place in the models, as he would be glad to show anyone who cared to see and examine both the models and the test specimens. Only one model could be ruptured, and in that the joint has not taken this form, and the line of rupture is not inclined, but square to the plate.

He could not even admit Mr. Walliker's forlorn plea, that even if the present rules are wrong they are good enough, and err on the right side, because it is bad engineering to use a factor of safety of 10 to 12 in the shell plates while all the other parts, which are far more subject to wear and tear, have only a factor of 5 to 6. The best working and lasting structure is one of uniform strength, and to insist upon carrying additional weight, which is not only useless, but mischievous, and to increase the first cost in order to get an inferior article is an unmitigated evil. To hint that because we now build good boilers we need not try to build better, is opposed to the whole spirit and function of this Institution, as it is to the spirit of progress which has brought our practice to its present high level.

To sum up this argument, the attempts to explain away the fact tha. these models sustained a pressure about double of that possible by accepted theory, had completely broken down. The theory itself had been proved to be based on an omission, and can only be supported by arguments which are palpably unsound. The theory proposed by him last year was also wrong from omitting to take into consideration one of the factors in the problem, namely, the distribution of shearing strain. The amended theory now before them takes into consideration all the possible ways in which the shell plates of boilers can be affected by pressure, namely, circumferential tension, bending moments, and shearing stress. It shows how these must be distributed up to the elastic limit, what happens after that limit is of no practical consequence to the boiler maker. While asserting that his theory is true as far as it goes, he admits it is not complete, as the relation between the shearing resistance of the plate and the actual and relative dimensions of the boiler is not determined, and so far as he can judge, can not be determined without further experiment.

The PAST-PRESIDENT said he would not attempt to follow the various gentlemen who had spoken. They were very much indebted to Mr. Spence and to the gentlemen who had co-operated with him in these experiments. These experiments were very satisfactory; they had been carried out honestly and fairly, and the paper was before the Institution. The discussion had been very valuable, and gave them much information. He begged to move a vote of thanks to Mr. Spence for his very valuable paper.

The proposal was cordially received.

The meeting then adjourned.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

EIGHTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON MONDAY EVENING, MARCH 23RD, 1891.

R. L. WEIGHTON, ESQ., M.A., VICE-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Newcastle, on March 9th, which were approved by the members present, and signed by the Vice-President.

The SECRETARY read a paper on "Electrical Engineering, with Special Reference to Electric Lighting" by Mr. W. C. Mountain.

ELECTRICAL ENGINEERING, WITH SPECIAL REFERENCE TO ELECTRIC LIGHTING.

By W. C. MOUNTAIN.

[Read before the Institution in Newcastle-on-Tyne, March 23rd, 1891.]

The writer of this paper proposes to deal generally with electric lighting, as this branch of electrical engineering is unquestionably of more interest to the engineers and shipbuilders on the North-East Coast than other branches, such as the telephone and the telegraph.

Before the various systems of electric lighting can be clearly explained it becomes necessary to give a short explanation of the electrical terms and units used in practical work.

The practical units, which correspond to the pressure and foot-pounds as used by engineers, are the volt, the ampère, and the ohm, and also the watt.

The volt is the unit of electro-motive force or pressure, and is usually written E.M.F. The legal volt is the electro-motive force which maintains a current of one ampère in a conductor whose resistance is a legal ohm. In speaking of volts or E.M.F., the electrical engineer uses this term in the same way that an engineer, accustomed to steam practice, uses pounds pressure per square inch, and when he speaks of a machine giving an E.M.F. of so many volts he means that the machine gives an electrical pressure which to an engineer conveys the idea of so many pounds pressure per square inch.

The volt is equal to one hundred million C.G.S. units of E.M.F., or about 7 per cent. less than the E.M.F. of a standard Daniell's cell (the E.M.F. of a standard Daniell's cell being about 1·1 volts), which is, as is well-known, a primary battery consisting of copper and zinc elements, the copper being immersed in a solution of sulphate of copper, and the zinc in a solution of sulphuric acid and water, the two elements being divided by a porous pot.

E.M.F. is equivalent to the difference of potential between two points.

The ampère is the unit of current, and to describe it practically, the

ampère is that amount of current which decomposes ·00009324 grammes of water per second, or deposits 4·025 grammes of silver per hour, and 886·4 ampères will deposit 1 lb. of copper per hour.

The next unit is the ohm, which is the unit of resistance, and is equal to the resistance of a column of pure mercury one square millimetre in section, and 106 centimetres long at a temperature of melting ice.

In order to still further convey the meaning of these units, and to provide for a practical way to apply them, a further unit, namely, the watt, is used, the watt being equal to 1 volt-ampère. A watt or volt-ampère represents the amount of work done by the dynamo or generator in a second, and, assuming that a dynamo is giving a current of 100 ampères at an E.M.F. or pressure of 100 volts, these multiplied together give 10,000 volt-ampères or watts, total output of the machine. 746 watts or volt-ampères are equal to one electrical horse-power, and corresponds to the 33,000 foot-pounds per minute used in engineering as the standard horse-power.

Therefore in order to ascertain the horse-power required to drive a dynamo of any given capacity, the total number of watts have to be divided by 746, which gives the electrical horse-power generated. Of course, as no dynamo is capable of giving out the whole of the power put into it, the electrical and commercial efficiency of the machine has to be taken into consideration, but as good dynamos of reasonable size are capable of converting 96 per cent. of the actual power put into them into electrical energy, and also as the total commercial efficiency of good machines is as high as 90 to 93 per cent., and in some cases slightly higher, it follows that the formula for working out the actual power required to drive a dynamo is, assuming the efficiency at 90 per cent., $\frac{10{,}000 \times 100}{746 \times 90} = 14{\cdot}89$, or say 15 horse-power on the dynamo pulley for a dynamo generating 10,000 watts, or what is known as a 10 unit machine.

This power is usually described as brake horse-power, and of course the indicated horse-power necessary to produce a given brake horse-power varies in different makes of engines, but assuming that the brake horse-power of an engine, to be on the safe side, is 75 per cent. of the total indicated power, then an allowance equal to this has to be made between the brake horse-power and the indicated power in estimating the size and power of the engine required.

Under the provisions of the Electric Lighting Act the Board of Trade has issued regulations in which 1,000 watt-hours of electrical energy are termed one unit. It is therefore customary to give the output of a dynamo

as of so many units, calculated from its output in watts divided by 1,000, the pressure and current being suited to the work for which the dynamo is intended.

In charging for a supply of current it is usual to make a charge of so much per unit, a unit of current, as an example, being the quantity required to feed 15 to 16 16 candle-power incandescent lamps for one hour, assuming that each 16 candle-power lamp requires about 60 watts.

Another unit which we shall have to deal with in the course of this paper is the line of force. The expression lines of force is used to explain the amount of magnetism produced in a bar of iron by the magnetising coil placed round it, and it has been found by experiment that good soft iron is capable of being magnetised to an intensity of about 20,000 lines of force per square centimetre of cross section, and for cast iron about 11,000, or say 130,000 per square inch for wrought iron and 70,000 for cast iron; but it is not customary to work to this high induction in dynamo designing, because it is too near the point of saturation, this being a point where any increase of magnetising power in the coils does not give a proportionate increase in the strength of the magnet.

An electro-magnet consists of a bar of wrought or cast iron upon which a coil of wire is wound, the lines of force being produced when a current of electricity flows through the magnetising coil. Assuming that the coil is wound right-hand, then a current entering the coil at one end and passing out at the other end would magnetise the bar in such a way that the north pole would be on the left-hand side of a figure swimming with the current.

Without going into fundamental units it will be sufficient to state that one hundred million lines of force cut in one second by a wire produces an E.M.F. of one volt. From this unit we are therefore able to calculate the exact E.M.F. which a dynamo should give when driven at a given speed with a given number of conductors wound round the armature, of course, assuming that the magnets give a magnetic intensity of so many lines of force per square inch section.

Having now described the practical units we are able to understand more clearly the construction of a dynamo electric machine, and as the chief item in an installation of electric light is the dynamo, and as it requires to be thoroughly understood by engineers and shipbuilders, the writer hopes that he will be excused if the explanation, which he proposes to give, is somewhat longer than would appear necessary.

The design of all dynamos is based on the fact discovered by Faraday, in 1831, that a current of electricity is generated in conductors by moving them in a magnetic field.

Faraday's principle may be described as follows:—When a conductor is moved in a field of magnetic force in any way so as to cut lines of force, there is an E.M.F. produced in the conductor in a direction at right angles to the direction of the lines of force, and to the right of the lines of force as viewed from the point from which the motion originates. This may be more clearly explained by *AMPÈRE'S* rule. Supposing a figure swimming in any conductor to turn so as to look along the (positive direction of the) lines of force, then if he and the conductor be moved towards his right hand he will be swimming in the current induced by this motion.

A dynamo electric machine consists of three essential parts, the field magnets, the armature, and the commutator. For the purpose of explaining more clearly the construction of a dynamo an illustration (No. 1, Plate XXVII.) is given showing a Tyne two-pole continuous current dynamo in section.

The field magnets are of soft iron, and on reference to the illustration it will be observed that they are in the shape of a U, commonly known as the horse-shoe magnet, the yoke being cast in the bed-plate and forming a portion of the magnetic circuit.

On the magnet the magnetising coils are placed, these being wound in one or other of the various ways which will be described later on. The armature which revolves between the north and south poles of the field magnets is coloured blue on the illustration, and consists of a gun-metal core upon which charcoal iron wire is wound between plates until the requisite diameter is obtained, the wire being wound under heavy tension so that the resulting core is extremely solid, compact, and true.

The reason for laminating armature cores is to prevent the formation of eddy currents and consequent heating in the core. Whether the core is composed of thin, soft iron plates, as in the drum and cylinder type, or of wire as shown, it is necessary to divide the surface into planes parallel to the lines of force and to the direction of motion. (Reference will be made later on to other types of armatures, but this does not affect the general description of the action of a dynamo.)

After the armature core is wound the copper conductors are wound upon it at right angles to the direction of rotation. The conducting wires on the armature are insulated with a double covering of cotton, or braided with cotton or silk covered as the makers may decide, but before the sections are wound upon the armature core it must be carefully insulated, so that there is no fear of the copper conductors making contact with the

iron, otherwise leakage of the current from the armature conductors to the iron core of the armature through the frame of the machine to the earth would occur.

In order to more clearly explain the construction of the armature core the writer exhibits a core wound with iron wire and also a core wound with the copper conductors, and it will be noted that these copper conductors are wound in sections and joined, so that they form a continuous coil round the armature, the inside end of one section being joined to the outside end of the next section, the two ends being brought down to join to the commutator.

The number of turns of wire on the armature and the section of wire depend on the E.M.F. and the current which the machine has to give when finished, and of course the actual number of armature turns is calculated on the formula that one hundred million lines of force have to be cut in one second to produce one volt. It may here be mentioned that it is the current or ampères which heats the wire, and not the volts or pressure.

To illustrate this explanation as to the E.M.F. generated in an armature we will take as an example a dynamo which is magnetised, so that four million magnetic lines are forced through the armature core by the field magnets. The armature is wound with 160 convolutions, and runs at a speed of 1,050 revolutions per minute. The E.M.F. is therefore—

$$\frac{4{,}000{,}000 \times 1{,}050 \times 160}{60 \times 100{,}000{,}000} = 112 \text{ volts.}$$

The commutator consists, in all continuous current machines, of a number of copper bars corresponding to the number of sections in the armature. The method of constructing the commutator varies with different makers of dynamos, but on reference to the sectional drawing (No. 1, Plate XXVII.) it will be observed that the copper bars are mounted upon a gun-metal sleeve, the ends of the commutator bars being recessed with a V into which the V-shaped collars fit, and the whole is locked together by the lock nut at the end of the sleeve. This method of construction has the advantage that it enables the commutator to be bodily removed from the machine without disturbing the sections, which is sometimes a matter of great importance where it is desired to put on a new commutator in the least possible space of time.

The copper commutator sections are insulated with mica, the ends of the copper sections being also insulated from the gun-metal sleeve, either by asbestos or in any other way which the makers may prefer. After the commutator has been placed upon the spindle the loose ends,

The E.M.F. in the armature, and consequently the current, is generated in one direction as the armature leaves the magnet pole, and in the opposite direction as it approaches the magnetic pole of the opposite name; therefore it will be seen that the object of the commutator is to commutate the current so that the two currents, flowing in opposite directions, are brought together and pass out through the positive brush to the outer circuit, returning through the negative brush to the armature.

The continuous current dynamo is, of course, constructed in other than the two-pole types, and for large output the writer has designed a four-pole dynamo, which is similar to illustration No. 2, Plate XXVII. For very large machines the number of poles have been still further increased in various types of dynamos. Amongst these may be mentioned the Gulcher dynamo, as made by the Gulcher Electric Company, Limited, the Kapp dynamo for central station work, made by Messrs. Johnson & Phillips, and the Victoria dynamo, as made by the Brush Company.

The advantage of increasing the number of poles in dynamos of large capacity consists in the increased ventilation in the armature due to the larger diameter, and consequently increased surface, of armature passing through the air, also the fact that the armature conductors are smaller in size. The resistance of the armature is also very low, the current being divided into four, six, or eight paths in parallel, in accordance with the number of poles in the dynamo, and also to the fact that it is somewhat difficult in large polar surfaces, where the reaction of the armature, due to induction, is considerable, to maintain an even field, without which sparking at the commutator is likely to occur.

The next type of dynamo which has recently come into considerable use is the alternating current machine, which, as the name implies, generates a current flowing first in one direction and then in the other. A dynamo of this description is illustrated by drawing No. 3, Plate XXVII., and it will be observed that it differs from the continuous current dynamo in the following important features:—

The field magnets are increased in number and placed radially round the armature, being united by the framing of the machine, which forms the yoke to the electro-magnets. In the machine illustrated there are ten magnets, arranged alternately north and south.

The armature of an alternating current dynamo differs from the continuous current dynamo somewhat considerably, although the construction of the armature core is practically the same, with the exception that the section of core is considerably greater in proportion to the section of the field magnets than it is in the case of the continuous current machine;

for the reason that, when iron—which is magnetised—passes rapidly between alternate poles, the rapid magnetisation and demagnetisation of the iron produces excessive heating if the iron is too highly magnetised; therefore, in order to reduce the strength of magnetisation, the section is increased so that the total density of lines of force passing through the armature does not exceed about 40,000 lines per square inch section.

On the periphery of the armature ten coils are wound, corresponding to the number of magnets, these coils being connected together in such a way that the current through the armature is in one direction when the coils are passing through one set of magnet poles, but in the opposite direction when passing through the next set of poles. The ends of these coils are connected to two collecting rings, insulated from each other by ebonite, or any other thoroughly efficient manner.

Of course, in alternating current machines, the current generated by the machine itself cannot be used for exciting the field magnets, because it is necessary that their polarity should remain constant, which would not be the case with alternating currents. It is therefore customary to excite the magnets from a small continuous current machine, which is termed the exciter, the exciter being driven either by an extension of the dynamo spindle or independently, at the discretion of the designer.

A small alternating current dynamo, capable of running 200 16 candle-power incandescent lamps, and constructed to give an output of from 12 to 14 ampères at an E.M.F. of 1,000 volts, is exhibited to more clearly explain this description.

Having now briefly described the construction of a dynamo, it becomes necessary to consider the class of dynamo most suitable for a given duty, that is to say, whether the machine is to be used for driving incandescent lamps in parallel, arc lamps in series, for charging accumulators, or for electro-plating or depositing.

In order to explain the difference between series, shunt, and compound wound dynamos, illustrations Nos. 4, 5, and 6, Plate XXVIII., are shown.

Dr. John Hopkinson was the first to suggest the representation of the properties of a dynamo, or the relations subsisting between the E.M.F. and the current by curves, which are now called characteristic curves. The curves correspond to the indicator diagrams of a steam engine, and by plotting out these curves from actual machines it is possible to know just as much about a dynamo as about a steam engine.

On reference to illustration No. 4, which represents a series dynamo, it will be seen that the current passes from the positive brush round the magnets to the outer circuit, and returns through the negative brush to

the armature. The characteristic curve of this dynamo is shown by illustration No. 7, Plate XXIX. The vertical line, which is divided into ten parts, represents the E.M.F. of the machine, and for the purpose of explanation, the E.M.F. is assumed to be 100 volts. The horizontal line represents the current given by the machine, and is also divided into ten parts. The total current of the machine is assumed to be 100 ampères.

On starting the machine, the outer circuit being open, a very weak E.M.F., as before explained, is generated in the armature, but owing to the outer circuit being open, there is no increase until the current can flow from the positive to the negative terminal through some form of resistance, such as arc or incandescent lamps. If the external resistance is high very little current, naturally, passes through it, owing to the E.M.F. being low, but as this resistance is decreased, either by inserting more lamps in circuit, that is, in parallel, the E.M.F. of the machine rises because more current flows through the lamps, strengthening the magnets until sufficient current passes through them to bring the machine up to its full pressure, which is represented by the curved line rising from zero, and which, with a current of 70 ampères, brings the total E.M.F. of the machine up to 100 volts. At this point the magnets become saturated, that is to say, that the increased excitation due to extra current passing round them does not produce a corresponding increase of lines of force and consequently a higher E.M.F. The resistance of the armature, which is, of course, a constant, then has to be considered, and any additional current which may be taken from the machine reduces the total E.M.F., and the line of E.M.F. drops from 100 volts at 70 ampères to, say, 90 volts at 100 ampères.

It will therefore be seen that the series dynamo is unsuitable for incandescent lighting, but it is specially suited for arc lighting in series, as it is necessary in series arc lighting that a slight variation in resistance of the circuit, due to the feeding of the lamps, should not disturb the E.M.F. of the machine, otherwise the lamps would jump and the light be continually varying.

No. 5 illustration, Plate XXIII., represents the connections of a shunt wound dynamo, and it will be seen that the field magnets form a shunt to the main circuit from the brushes. On reference to the diagram representing the action of a shunt wound machine it will be seen that upon the machine being started the E.M.F. rises up to the full E.M.F. for which the machine was designed, *i.e.*, 100 volts, whether there is any work on the machine or not, because the magnets producing a weak E.M.F. sets up

an E.M.F. in the armature which sends a weak current round the shunt coils of the magnet, strengthening them until the full E.M.F. of the machine is obtained.

When work is put upon a shunt wound dynamo the E.M.F. in the armature is reduced in proportion to the current flowing round it. For instance, supposing that the armature has a resistance of ·1 of an ohm, and a current of 100 ampères was passing round the armature coils, the drop in E.M.F. would be 10 volts, because the drop of pressure in a wire, whether on an armature or a main conductor to the lamps, is found by multiplying the resistance of that armature or conductor in ohms by the current in ampères flowing through it. It will thus be seen that when the total current of 100 ampères is being taken from the machine the E.M.F. is reduced by 20 volts, bringing the resultant E.M.F. in the outer circuit to 80 volts, as shown by diagram No. 8, Plate XXIX.

In this calculation the resistance of the armature alone has been taken into consideration for simplicity's sake, but in addition to this there is the loss due to the smaller current passing round the magnets at the lower pressure which would make the resultant E.M.F. still lower.

It will be seen from this description that a shunt wound machine is not suited for running incandescent lamps unless a variable resistance is placed in the field magnet circuit, and regulated so that the amount of current passing through the magnets exactly keeps the pressure constant; but in practice it is found far better to make a self-regulating dynamo which will keep the E.M.F. constant whatever the load in the outer circuit may be.

The shunt wound dynamo, however, is used for charging accumulators, because in the event of the dynamo stopping or running at such a speed that its E.M.F. is less than the E.M.F. of the accumulators, the current which returns from the accumulators passes round the magnets in the same direction as the current from the machine itself, and consequently does not demagnetise the magnets, as it would with a series wound machine.

Illustration No. 6, Plate XXVIII., represents the winding of a compound wound dynamo, which is now almost universally adopted for running incandescent or arc lamps in parallel. It will be seen on reference to the diagram that the magnets are wound with a double winding, one winding being shunt and the other series. When the machine is started, and when the only current generated is the current passing round the shunt coils, the dynamo gives its full E.M.F. of, say, 100 volts.

The series coils, which are shown by the thick lines, are connected so that the main current passing from the brushes to the outer circuit flows round them, increasing their strength in such a proportion that whatever the amount of current may be in the outer circuit the magnets are so increased or decreased in strength that they exactly produce a correspondingly greater or less E.M.F. in the armature, which compensates for the loss due to the resistance of the armature giving a constant pressure in the outer circuit whatever the current may be It is usual, however, to so wind the magnets that the E.M.F. falls slightly at light load, allowing for any slight increase of speed in the engine. This is represented by illustration No. 9, Plate XXIX.

This system of compound winding was originally introduced by Varley, the object of the shunt coil being to give the machine a start.

These explanations respecting the characteristic curves and properties of different kinds of dynamos, apply not only to the two-pole dynamo, but all other classes. For instance, the type shown in illustration No. 1, Plate XXVII., represents as far as the general magnet arrangement is concerned, the machines manufactured by Messrs. Ellwell Parker, W. H. Allen & Co., Paris & Scott, W. T. Goolden & Co., etc. The inverted magnet, *i.e.*, with the magnets turned the other way, the yoke being at the top, represents the machines built by Messrs. Holmes & Co., Mather & Platt, The Silvertown Co., Latimer, Clark, & Co., etc.

The multipolar dynamo, that is, with four or more poles, is manufactured by Messrs. Johnson & Phillips, The Brush Co., The Gulcher Co., and the writer's firm, Messrs. Ernest Scott & Mountain. The principal difference, however, in these types of dynamos is in the construction of the armature, and illustrations Nos. 10, 11, and 12, Plate XXX., show the three types of armatures in common use.

Illustration No. 10, Plate XXX., represents the drum armature, which was originally invented by Hefner von Alteneck, of the firm of Messrs. Siemens & Co., and was really a modification of the original Siemens's shuttle wound armature used in the old Wilde machine. In the drum type of armature, as originally made by Messrs. Siemens, the core was constructed of a wood boss mounted on a spindle, but hollowed out in the centre, and filled up with iron wire wound into the recess, over which copper conductors were wound. Dr. John Hopkinson then made considerable modifications in the design of the Edison machine, and produced what is now known as the Edison-Hopkinson dynamo.

The armature of this machine is made up of a number of thin, soft iron washers mounted upon a spindle and secured at one end by a flat wrought

iron washer butting against a collar on the spindle, and at the other end by a washer and lock nut. This makes a very strong mechanical arrangement, and is now more or less copied by the whole of the dynamo makers manufacturing this type of armature. The copper conductors are wound over the surface of the core lengthways, like a shuttle.

Illustration No. 11, Plate XXX., represents the Gramme armature now known as the cylinder or ring armature. Gramme originally invented this armature about the year 1871, and it was constructed by winding iron wire on a former or mould. When the wire had been wound up to a sufficient thickness and length the mould was removed, and the conducting wires wound lengthways on the outside of the core, returning through the inside, the number of turns and sections depending on the size and output of the machine.

After the armature was wound it was driven tight on to a wooden hub, which was then put into the lathe, the armature set true, and a hole bored through the centre of the wooden hub into which the spindle was fitted, the power for driving the armature being transmitted by the friction between the hub and the inside conductors on the armature core.

This arrangement was also very unmechanical, and the Gramme or cylinder armatures are now almost universally constructed with a number of thin iron washers with holes through the centre. These are cramped together, usually, between gun-metal drivers cut away, so that the wire can be wound in between the arms, the conducting wires being wound in sections on the outside, returning through the centre hole, and then joined in the usual way to the commutator.

Illustration No. 12, Plate XXX., represents the disc armature. The core is constructed in various ways by different manufacturers; but the usual practice is either to wind it up with thin hoop iron or else with rectangular wire, as in the Tyne dynamo, the iron core being supported by an internal ring with driving arms.

From these diagrams it will be seen that the chief point which dynamo manufacturers have aimed at is to make a thoroughly mechanical attachment between the armature core and the driving spindle, the iron plates, washers, or wire, being so arranged that eddy currents are not generated, and heating of the core is avoided.

Having now described the different classes of dynamos suited for the different systems of installation work, diagrams Nos. 13 to 19, Plates XXXI. and XXXII., illustrate the various systems of distribution in general use, which may be briefly summarised as the Parallel system, Series system, and the Three-Wire system.

The parallel system is represented by diagram No. 13, Plate XXXI., in its simplest form, and it will be noted that the positive and negative wires are taken along side by side, *i.e.*, parallel with each other, and the lamps joined across at intervals where required. In this system it must be remembered that it is usual to work with a constant E.M.F. between the dynamo terminals, therefore the amount of current generated by the dynamo is exactly in proportion to the number of lamps which are burning, because the current given out by the machine naturally depends upon the resistance in the outer circuit, and the fact of putting in more lamps reduces the resistance between the positive and negative wires allowing more current to pass.

Diagram No. 14, Plate XXXI., represents the same system, but with branches running in various directions, and it will be noted that the same general principle is carried out, and this may be taken as a fair representation of a small incandescent light installation. The dynamo is marked D, and a main double-pole switch is placed next to the dynamo. From the main switch board two vertical mains are run, and the branch mains are tapped off where required. It is desirable to put a fusible cut-out, which usually consists of a slate or china base with two terminals connected between the wire in such a way that the current passing along the wire has to pass up one terminal through a length of tin fuse wire to the other terminal and then along the cable. The object of this cut-out is to provide that if a short circuit should occur, that is, the two wires come in contact and an excessive current pass through, the tin fuse wire melts and the current is cut out.

In working an installation upon the parallel system, which is the system in use throughout all classes of ship work and low tension incandescent electric lighting, it is necessary to proportion the section of cables so that they will safely carry the current required without heating, and also to provide against an excessive drop of potential between the dynamo and the lamps.

The fire insurance companies have now issued rules in which they state that a density not exceeding 1,000 ampères per square inch section of copper in the conductors is permissible, and it is found in practice that this density is an extremely satisfactory one, at any rate, for small conductors carrying up to one or two hundred lamps.

Assuming that a cable has to carry a given number of lamps the size is readily found by reference to the tables which are used by the cable makers and electric light engineers. The following is a copy of a table which will be useful for reference:—

TABLE No. XIII.

	Diameter.		Sectional Area. Inch.	Resistance per 100 yards.	Carrying Capacity 1,000 per sq inch.	Number of 16 C.P. 65 Volts.	Number of 16 C.P. 100 Volts.	Number of 2,000 C.P. Tyne Arcs.
	Inch.	M/m.						
				Ohms.				
	·028	·711	·0006	4·1616	·06		1	
	·036	·914	·0010	2·4607	1·0	1	1	
	·040	1·02	·0012	2·0387	1·2	1	2	
	·048	1·22	·0018	1·4168	1·8	2	3	
	·056	1·42	·0024	1·0404	2·4	3	4	
	·064	1·62	·0032	·7894	3·2	4	6	
	·072	1·83	·0040	·6239	4·0	5	7	
	·080	2·03	·0050	·5098	5·0	6	9	
	·092	2·34	·0066	·3855	6·6	8	12	
2	·104	2·64	·0085	·3026	8·5	10	15	1
1	·116	2·94	·0105	·2424	10·5	12	19	1
0	·128	3·25	·0128	·1991	12·8	15	23	
7/22	·084	2·13	·0044	·58537	4·4	5	8	
7/20	·108	2·74	·0072	·35436	7·2	9	13	1
7/18	·144	3·66	·0128	·19920	12·8	15	23	
7/16	·192	4·88	·0229	·11207	22·9	27	40	2
7/15	·216	5·49	·0289	·08854	28·9	34	50	3
7/14	·240	6·10	·0356	·07190	35·6	42	64	4
19/20	·180	4·57	·0198	·12975	19·8	23	35	2
19/18	·240	6·10	·0349	·07293	34·9	40	63	4
19/16	·320	8·12	·0624	·04105	62·4	72	112	7
19/15	·360	9·14	·0789	·03243	78·9	92	140	9
19/14	·400	10·1	·0973	·02628	97·3	112	172	11
19/12	·520	13·2	·1647	·01554	164·7	190	290	18
		11·3						
37/16	·448		·1219	·02100	121·9	143	220	14
37/14	·560	14·2	·1909	·01344	190·9	220	340	24
37/12	·728	18·4	·3217	·00795	321·7	370	570	40

The above table is worked out at 56 watts.

An ordinary 16 candle-power 100 volt incandescent lamp requires 60 atts to feed it. In ship work it is usual to make the E.M.F. from 60 to volts, as this E.M.F. is suitable for working arc lamps and projectors. his E.M.F. of 60 volts necessitates a current of 1 ampère being used for ch 16 candle-power lamp, or by working at 100 volts ·6 of an ampère required. Assuming that it is required to feed 100 lamps, it will be und that a cable composed of nineteen wires, No. 14 L.S.G., has a sectional ea of ·0973 of a square inch, and is therefore capable of carrying 97·3 mpères. The 100 lamps would require 100 ampères, which is near ough for practical purposes.

The next point to be considered is the drop of potential at the end of cable when the whole of the lamps are burning. The resistance of 100 rds of 19 14 cable is ·026 of an ohm, which, multiplied by the current, 100 ampéres, gives a drop of potential of 2·6 volts, that is to say, that

each 100 yards of cable absorbs practically 2½ volts when working at a density of 1,000 ampères per square inch section of copper, so that the dynamo has to be constructed to give a slightly higher E.M.F. than the potential actually required at the terminals of the lamps to provide for the loss due to the resistance of the leads.

If the lamps are at a considerable distance from the dynamo, and it is desired to get anything like regulation over the whole of the circuit, the section of copper, of course, has to be increased to provide for this.

Diagrams No. 15, Plate XXXI., represents the series system, which is usually used for arc lighting. The arc lamps (or incandescent lamps, if it is proposed to run incandescent lamps on this plan, which is never done except for street lighting) are joined in series, the current at a high E.M.F. passing from the dynamo through the lamps in series, *i.e.*, one after the other, and back again to the dynamo. In running arc lamps in series it is customary to allow about 50 volts per lamp, so that with 10 lamps in series it would require an E.M.F. of 500 volts; and assuming they were 10 ampères, *i.e.*, 2,000 candle-power nominal arc lamps, a current of 10 ampères is necessary.

It will be seen at a glance that the economy of this system depends upon the fact that, instead of increasing the current as is done in the parallel system, the E.M.F. is increased, consequently the cost of the cable is only one-tenth of what it would have been if the 10 lamps had been run in parallel, when a current of 100 ampères, that is, 10 ampères per lamp, would have been required, necessitating a cable of 10 times the sectional area. This system is largely used for lighting streets, docks, or large distributed areas.

Diagram No. 16, Plate XXXI., represents the three-wire system, which was originally invented by Edison, and has been much used by him in lighting towns in America. This system is now finding considerable favour in England for the lighting of compact areas where there are a large number of lamps required. Two dynamos are joined in series, as shown, so that, assuming they are 100 volt machines, the total E.M.F. of the two machines joined together is 200 volts.

A main positive wire and a main negative wire, with a difference of potential between them of 200 volts, and a third wire of smaller section, which is called the intermediate wire, the latter being connected between the positive and negative terminals of the dynamo, are run from the dynamo to the point where the lights are required, say along a main street. The branches for the houses to the right-hand side of the street are tapped off between the intermediate wire and the outer main wire on

the right-hand side. The branches for the houses on the left-hand side of the street are tapped off between the left-hand main wire and the intermediate wire.

Assuming an equal number of lamps are burning on each side of the street, the whole of the lamps are two in series, the centre wire carrying no current; but in the event of the number of lamps burning on one side of the street being greater than on the other side, the centre wire carries back to the dynamo any difference in quantity of current between the two sides. It is therefore only necessary to make the two outer wires large enough to carry the current at an E.M.F. of 200 volts, the centre wire being of sufficient capacity to carry any probable difference in current there may be between the lighting on one side and the other.

The cost of cables by this system is slightly over half what they would cost if the two dynamos had been run in parallel at 100 volts each, because the cost of a conductor, as previously stated, depends not upon the E.M.F., but on the current.

A system of incandescent lighting, which was at one time used on the high tension arc light circuits at Eastbourne and several other places, is shown on Diagram 17, Plate XXXI.

Assuming that the difference of potential between the dynamo terminals was, say, 1,000 volts, and that 800 volts were required to work 16 arc lamps, four groups of 50 volt incandescent lamps could be arranged in series, as shown on diagram. The current would pass through the arc lamps, then through the incandescent lamps, and back to the dynamo. If the working current is 10 ampères the incandescent lamps would be arranged to take 1 ampère each, *i.e.*, 50 watts; but the great objection to this system has always been that in the event of one lamp breaking the remainder of the lamps have to take the whole of the current, the reason being that the one lamp forms such a small total of the whole resistance of the circuit that the 10 ampères flowing would be divided amongst the remaining nine lamps, which would very quickly cause them to break through over running, *i.e.*, running them above their normal candle-power.

Several magnetic devices have been introduced, so that in the event of a lamp breaking a resistance equal to the lamp is switched into circuit, or another lamp switched in; but, unfortunately, nearly all magnetic arrangements of this kind, although they work excellently in a laboratory, seem to fail when used in practical work.

This system, however, has been very little used, and the description is only given to explain how incandescent lamps can be run on an arc lighting circuit for the benefit of those who may have an arc light dynamo and require to run a few incandescent lamps.

Diagram No. 18, Plate XXXII., represents a system originally tried at Colchester, and has since been adapted by the Chelsea Supply Co. The dynamos are high tension machines, a small main cable making a complete circuit round the district to be lighted. The accumulators are fixed at various points on the circuit and charged in series, the current for lighting the lamps being taken from the accumulators when they are switched out of the charging circuit. Of course, a set of accumulators can be used for lighting one house or for a group of houses, the lamps being tapped off the accumulators in parallel as illustrated.

Diagram No. 19, Plate XXXII., illustrates a low tension distribution scheme which has been carried out at several supply stations in England and abroad. The arrangement consists of feeders branching off from the main supply station to a number of points about equidistant from the generating plant. The current is then fed into ring mains which can either both run round together, or one wire may be taken round in one direction and the other in the reverse direction, as shown on the diagram, which gives an equal E.M.F. over the whole system. Of course, branches are tapped off on either side of the ring mains for feeding the lamps within a reasonable distance.

Diagram No. 20, Plate XXXIII., shows the general arrangement of a dynamo and set of accumulators as used for isolated installations, such as private houses or distribution schemes on the accumulator system. On reference to the diagram it will be seen that the positive pole of the dynamo is connected to the main charging switch on the main switch board, the negative pole of the dynamo being connected to a five or more contact switch.

Between the main charging switch and the dynamo an automatic cut-out and an ampèremeter is placed, the former being arranged to automatically switch in and out the charging circuit when the dynamo is started or stopped, or if the E.M.F. of the dynamo should by accident fall below the E.M.F. of the accumulators, and thus prevent any possibility of the armature coils of the dynamo being burnt up by the return current from the cells, the latter measures the current passing into the accumulators or outer circuit from the dynamo.

By means of the cross-bar on the main switch the contact block connected with the positive terminal of the dynamo, marked D1, can be connected direct to the positive terminal of the accumulators, marked A, the negative five-contact switch being also joined to the last five cells of the accumulators, the stud connected to the handle of the switch being joined to the negative pole of the dynamo, so that by moving the

handle so that the tongue bears on any one of the five contacts the negative pole of the dynamo is connected to the accumulators. Charging then commences, and when the cells are fully charged, which can be ascertained by the sulphuric acid and water having apparently turned milky, or the specific gravity ascertained by means of a hydrometer, the switch is moved so that the second contact L on the charging switch is joined to the first contact A communicating with the accumulators. The tail end of the switch on the long sliding contact D1 now bears on an insulated block and disconnects the dynamo from the accumulators, the current passing from the accumulator terminal A to the lamps through the terminal L.

To run the dynamo and accumulators together it is only necessary to move the cross-bar of the switch round a little further when the current from the dynamo terminal D passes across the cross-bar of the switch and the current from the dynamo is united with the current flowing from the accumulators, both currents passing out together through the lamp circuit terminal L direct to the lamps. By moving the switch round a little further the accumulators can be cut out, and the dynamo feeds the lamps direct, the current passing from the terminal D across the cross-bar and out through the terminal L.

The object of the five-contact switch on the negative pole of the dynamo is to enable extra cells to be switched in after discharge has taken place for some little time to compensate for the drop of potential which takes place when the cells are partially discharged, by adding one or two extra cells as required, each cell adding 2 volts extra pressure.

It is customary to fix a voltmeter for all accumulator installations so that the E.M.F. at the terminals of the dynamo and the accumulators can both be read when required.

Accumulators, in anything like a practical form, were introduced by Plante, and at that time consisted of a number of plain lead plates immersed in a solution of sulphuric acid and water. The plates had then to be formed by passing a current of electricity into them, which oxidised the positive plate. The current was then reversed when the oxidised plates were gradually turned to spongy lead, the negative plates then became the positive plates, being coated with lead oxide. This action was again reversed until there was a good coating of oxide on the positive plates and the negative plates became like spongy lead. As can be readily seen, this type of accumulator was very defective from the fact that when the cells had got into their best working condition they became so rotten that they fell to pieces.

Improvements in construction were taken in hand by Faure, Sellon, and Volkmar, who patented amongst them a system of forming the plates of lead grids filled in with lead oxide, the oxide blocks being inserted into the metallic grid in such a way that they would not fall out. These patents were acquired by the Electrical Power Storage Company, and Messrs. Ellwell Parker, of Wolverhampton, obtained a license to manufacture them under these patents. These concerns are, however, amalgamated, and known as the Electric Construction Corporation. The accumulators are made in various sizes, that is, the number of plates per cell is increased in the larger sizes, although the actual size of the plates is about the same. It is found by practice that the discharge which can be taken from an ordinary accumulator is about 4 ampères per positive plate.

A new type of cell for rapid discharges has been introduced very lately; in this type the discharge can be as high as 8 ampères per positive plate.

A set of accumulators to run 100 lamps, seeing that the E.M.F. of each cell, when discharging, is 2 volts, consists of 50 cells, each containing 31 plates, the total E.M.F of the 50 being 100 volts, and the discharge which they are capable of giving, as a maximum in regular work, is 60 ampères, or 6,000 watts total output for 8 to 10 hours when fully charged. These cells, of course, are joined in series, as shown on the diagram, and the lead plates are either put into glass jars for land use, enabling the plates to be examined, or for traction purposes they are put into teak boxes.

Accumulators have been largely used not only for lighting, but for the storage of electricity for tram cars, electric launches, and a variety of other purposes, but there is an unavoidable loss, due to the difference between the charging E.M.F. and the output, because it is necessary to charge them at an E.M.F. of $2\frac{1}{2}$ volts per cell to overcome their counter E.M.F. and internal resistance, the discharging E.M.F. being only 2 volts. Notwithstanding this loss, however, the convenience of having a supply of electricity stored against emergency makes them very valuable for private house installations and for central stations on the parallel system.

Diagram No. 21, Plate XXXIII., illustrates the distribution of electricity by transformers. But before explaining this system it is necessary to give a brief description of the transformer itself.

Everyone is acquainted with the Rhumkorff induction coil, which is used for medical purposes, and for passing sparks of electricity at high tension through vacuum tubes. The action of an induction coil depends

upon the fact that when lines of force are generated in a bar of iron by the primary current, and the contact suddenly broken, a current of electricity is induced in the secondary coil surrounding the magnet. The transformer is really an induction coil, but without the make and break arrangement on an ordinary Rhumkorff coil, and in its simplest form consists of a bar of iron wound with two wires, the primary wire coils being connected between the mains of the high tension alternating system, the secondary wire coils communicating with the lamps.

Upon a current of electricity passing in one direction through the primary coils the iron is magnetised, but when the next wave of electricity passes in the opposite direction the iron is demagnetised and then magnetised in the opposite direction. This rapid magnetisation and demagnetisation of the iron produces lines of force which cut through the secondary coils and generate an E.M.F. and current in them, bearing an exact ratio between the number of turns of wire on the primary and the secondary coils. For instance, assuming a transformer working at 2,000 volts was wound with 2,000 turns of wire, it would be necessary to wind 100 turns of wire on the secondary coil to produce an E.M.F. of 100 volts, but as it is not only necessary to reduce the E.M.F., but to increase the current, the sectional area of the secondary wire is increased in diameter, so that it is 20 times the area of the primary.

A transformer as made by the writer's firm is shown on illustration No. 22, Plate XXXIV. A transformer is also exhibited capable of running 40 16 candle-power lamps. By means of this ingenious device, which has no moving parts and requires no attention whatever, the difficulties of high tension alternating current distribution has been solved, and all that is necessary is to run a pair of high tension mains, as shown on diagram No. 21, up a main street, placing the transformers on either side of the road, and simply tapping off the mains to the different houses, and connecting them to the transformers.

It is usual in high tension alternating current work to run the cables underground in iron pipes, cast iron junction boxes with water-tight covers being placed where required, so that branches may be tapped off at intervals to the houses. Some firms have used concentric cables, that is, a cable in which the current passes through the copper conductor in the centre, which is insulated from an outer conductor through which the current returns to the dynamo, this being also insulated so that there is no leakage to earth. The object of the concentric cable is to avoid induction in telephone wires. The objection to this class of cable is that it is more difficult to joint than two ordinary cables.

The alternating transformer system, owing to the high tension and the small section of the conductor necessary, is considerably less expensive than the low tension system in cost of conductors, because the sectional area of cable required in the low tension system, assuming the distribution at 100 volts, is as 20 to 1 in favour of the high tension at 2,000 volts. It would be impossible to economically distribute current over an area where the lamps are any distance from the dynamo by the low tension system, as the following calculation, showing relative efficiencies of the parallel low tension and alternating high tension systems on the basis of running 500 16 candle-power 60 watt lamps, 1,000 yards from the dynamo, the conducting cables having in both cases a sectional area equal to 1,000 ampères per square inch will show :—

Low Tension Continuous Current.

500 lamps each taking 60 watts require—

500
60

30,000 watts = 300 ampères × 100 volts.

To carry a current of 300 ampères you will require a cable consisting of 37 wires, No. 12 L.S.G., with a sectional area of ·321 square inches, and a resistance of ·078 per 1,000 yards.

Resistance ·078 ohms per 1,000 yards.

2

·156 per 2,000 yards, *i.e.*, out and home.
300 ampères.

46·800 = 46·8 volts loss in leads,

so the dynamo would have to give—

100 volts at lamps + 46·8 loss = 146·8 volts.
146·8
300 ampères.

44,040·0 watts.

$\frac{30,000 \times 100}{44,040}$ = 68 per cent. efficiency of system.

High Tension Alternating System.

500 16 candle-power 60 watt lamps require 30,000 watts, which at 2,000 volts is equal to 15 ampères of current.

15

ıı require a cable equal to
rea of ·0162 inches, and a

9 I

1·56 1

1 1,

3·12 per 2,000 yards out and home.

15 ampères.

---

15 60

31 0

46·60 = 46·6 volts loss in leads,

so the dynamo would have to give—

2,000 volts at transformer + 46·6.

46·6

2,046·6 volts at dynamo.

15 ampères.

10,233·0

20,466

30,699·0 watts.

$\frac{30,000 \times 100}{30,699}$ = 98 per cent. efficiency of system.

There is a small loss in the transformer of, say, 3 to 4 per cent.; but the total efficiency of the system at full load would certainly be as high as 92 per cent., against 68 per cent. on the low tension scheme.

Another feature in favour of the alternating current system is, that the E.M.F. at the lamps would be practically constant, whatever the load would be, whereas with the continuous current system the E.M.F., with one lamp on, would rise to 146 volts, unless it was automatically adjusted, and, of course, destroy the lamps.

The cost of the two systems, in cable only, would be approximately:—

	£	s.	d.
2,000 yards 37/12 cable	1,180	0	0
2,000 „ 1/9 „	83	0	0

This is a very important saving, seeing that the cost of laying a small cable is less than a large one.

Having now described the different classes of dynamos, and the various systems of electric lighting in practical use at the present time, the application of the electric light to steamships can be readily explained; and, to represent the two systems in use at the present time, the writer has prepared two diagrams, Nos. 23 and 24, Plate XXXV.

Diagram No. 23, Plate XXXV., shows an ordinary system of single wire distribution on board ship in its simplest form. A main conductor is run from one end of the ship to the other, connected to the positive pole of the dynamo marked D; the negative pole of the dynamo is connected to the iron or steel hull of the ship. The current is then tapped off from the positive main running fore and aft, through the incandescent lamps, which may either be in groups or singly, and the wire from the other side of the group of lamps connected to the hull, so that the hull of the ship acts as the negative return conductor to the dynamo. Of course it is usual, in ship installations, to divide the lighting up into several circuits: for instance, one circuit would be taken to the fore end of the ship and the other run aft, and probably a third circuit would be used for the engine room; but, however many circuits there may be, the diagram represents the actual system. Main switches are, of course, placed on a main switch board in the engine room connected to each of the circuits, with a fusible cut-out to each, so that, in the event of any short circuit, the fuse would melt, and prevent any possibility of fire. Where the lamps are tapped off these main branch switches should also be placed, and where the mains are reduced in sectional area cut-outs are also placed, because, although a large cable might not get hot, with a certain leakage a small cable would get dangerously hot and cause fire; therefore it is necessary to protect the smaller cable by a cut-out at its junction with the larger cable. Fusible cut-outs should also be placed in all positions where a single lamp is tapped off the main circuit and connected to the hull.

The double wire system is represented by diagram No. 24, Plate XXXV., and in this arrangement the whole of the electric light circuit is carefully insulated from the ship, there being a positive wire from the dynamo to the lamps and a negative return wire connected with the negative pole of the dynamo.

In this system of lighting it is also desirable to divide the installation into a number of circuits not only to provide against any possibility of a total breakdown in case of a circuit going wrong, but also to enable different parts of the ship to be lighted when required from the engine room, and thus place the control of the installation in the hands of the dynamo attendant or the engineer in charge.

In the double wire system the main distributing switch board is also

The writer exhibits various samples of cables which have been kindly lent to him by the India-Rubber, Gutta Percha, and Telegraph Works Company. These cables show the different classes of insulation, also lead covered and armoured cables, together with the different methods of jointing.

In jointing cables it is very necessary, not only to ensure that a perfect metallic joint is made, but also to avoid the use of any substances, when soldering, that is liable to cause injury to the wires. When jointing a straight stranded conductor consisting of 19 wires, the 12 outside wires must be turned back, leaving the 7 wires of the centre strand projecting; these are then scarfed, and the two laid together, after being thoroughly tinned. They are then bound together with fine binding wire—preferably tinned—and soldered with good hard solder, resin being used as a flux. Six of the outer wires in each end of the cable, *i.e.*, half the total number of wires, are then cut off, and the remaining 6 wires of each end of the cable laid together, forming a complete cable of 19 wires, *i.e.*, 7 inside and 12 outside. These are then bound with binding wire at each end, and the whole soldered together, so that a perfect metallic joint is made. This method of binding is illustrated by the samples exhibited.

After the joint is made, it should be bound with india-rubber strip, india-rubber solution being used to ensure a perfect joint between the several layers of india-rubber strip. After being well insulated with india-rubber, the joint should be bound with solution tape, which is a tape impregnated with a solution of india-rubber, and made waterproof on the outside. The joint is then finally finished by being coated with Chatterton's compound, which is a compound made of Stockholm tar, pitch, and several other ingredients, and makes the joint thoroughly waterproof.

In making a T-joint, *i.e.*, where a branch is taken from the main conductor—the strand is usually divided, one-half being twisted round the cable on the right-hand side and the other half twisted round on the left-hand side of the joint. The whole is then soldered with resin, and the joint finally completed, as before explained.

For high tension underground work still greater care has to be taken in jointing, and it is desirable to vulcanise the joints after they are coated with the india-rubber tape. This is done by placing the joint in a cast iron mould with sulphur, and keeping the temperature at 290 to 300 degrees until the whole is vulcanised together. The final insulation is the same as with the ordinary joint. A sample of a vulcanised T-joint is shown, explaining this description.

In ship lighting, where the space at disposal for the engine and dynamo is very limited, it is necessary to make them as compact, and at the same

time as efficient, as possible. Unfortunately, in many cases the engine and dynamo has not received the care and attention from the engineers on board ship that it should have done, probably because it has been stowed away in any hole or corner of the engine room where it has been practically impossible for the engineer to get at it, the result being that the engines have been allowed to knock themselves to pieces through want of attention to the lubrication and bearings, and the dynamos have gone wrong through the brushes not having proper care and attention bestowed upon their adjustment. However, this state of things is gradually improving, and in ships where the electric light is to be adopted proper provision is now made for the generating plant.

Drawing No. 25, Plate XXXVI., illustrates a vertical double-acting high speed engine coupled direct to the spindle of the dynamo, the power being transmitted direct from the crank shaft to the dynamo without any intermediate belting or gearing. The engine and dynamo are secured to a cast iron bed-plate, the whole being extremely rigid, and occupying very little space. This design of plant is about as compact as it is possible to make anything, except that it is run at an abnormally high speed.

The engine is of the double-acting type, fitted with a Pickering high speed governor and equilibrium throttle valve, and runs at a speed of about 350 revolutions per minute in the small sizes for running 50 16 candle-power lamps, and in the larger sizes, *i.e.*, plants capable of running from 100 to 250 lamps, at a speed of 300 to 200 revolutions per minute respectively. At these speeds, the stroke of the engine being of course short, the wear and tear is very small indeed, because the crank shaft of the engine works in a bath of oil, the splash from the crank webs lubricating the crank shaft bearings, connecting rod ends, and guide bars. Lubricating boxes are also fitted for the lubrication of the piston rod, valve spindle, and eccentric strap.

Of course in running a dynamo at the very slow speed necessary when coupled direct to an engine, the machine has to be considerably larger, and necessarily more expensive than it would be if driven at its normal speed of, say for a dynamo capable of running 100 16 candle-power incandescent lamps, 700 to 800 revolutions per minute, because the output of a dynamo is practically in proportion to its speed. To overcome this objection other types of engines and dynamos have been designed.

Drawing No. 26, Plate XXXVI., shows a combination of an engine and dynamo, in which an engine of the same type as already described is mounted at one end of a cast or wrought iron bed-plate, as preferred, the dynamo being placed at the other end, with very short centres. In order to ensure satisfactory running at the short centres a jockey pulley is

placed between the engine and dynamo, so that the belt running under the jockey pulley grips a considerable part of the circumference of the pulley, thus ensuring a good grip. This description of plant has been used on a number of ships with satisfactory results; and of course the first cost of a plant of this description is less than it would be for a combined plant as above.

One objection to this plant is that the belt has to be very tight, and it is therefore liable to cause heating of the bearings. To avoid this an arrangement, partly friction and partly belt driven, similar to drawing No. 27, Plate XXXVII., was, the writer believes, first introduced by Messrs. Alley & Maclellan, of Glasgow.

On reference to the illustration it will be seen that the friction pulley is placed between the engine fly-wheel and the dynamo pulley, the friction wheel being carried by a screw gear so that it can be wedged in between the fly-wheel and the dynamo pulley. An endless driving belt passes over the friction wheel and drives from the fly-wheel direct on to the dynamo pulley. It is therefore apparent that whatever thrust may be put on the bearings, by means of the friction wheel, is taken up by the tension on the driving belt, so that the bearings run almost in equilibrium.

A fourth type of plant, but one entirely driven by friction, is illustrated by drawing No. 28, Plate XXXVII. The vertical engine in this case is placed at the end of the bed-plate, the fly-wheel being carried on an extension to the crank shaft. The dynamo is hung in a cradle and arranged to swing in such a manner that the dynamo pulleys rest on the fly-wheel, the friction between the fly-wheel and the pulley being regulated by means of a spring.

It is usual to make these small friction wheels of compressed paper, which is fastened between two iron discs, the discs being bolted or screwed tight together and the paper turned up afterwards. Discs of leather have also been tried successfully.

The whole of the plants described are fitted with single cylinder engines, but, of course, for large installations consisting of several hundreds of incandescent lamps, and where it is necessary to work on the most economical basis, compound engines are frequently used.

The single cylinder type of engine as shown can be readily compounded by putting another engine at the side with a low pressure cylinder suitably proportioned. The open type of engine, *i.e.*, with cast iron or wrought iron back standards carrying the guide bars and wrought iron or steel front columns has also been considerably used for lighting both in the merchant service and by the Admiralty.

Messrs. Willans & Robinson, of London, Messrs. Alley & Maclellan, of

Glasgow, and Mr. Bumstead, of Hednesford, have introduced engines of the closed single-acting type, known as the Willans, Westinghouse, and Chandler engines respectively. These engines are either made simple, compound, or triple expansion, according to the pressure at which they are designed to work, the chief feature about them being that steam is admitted on to the top side of the piston only, keeping all bearings in constant thrust.

The advantage of this class of engine lies chiefly in the fact that they are able to run at much higher speeds than a double-acting engine, because of their freedom from knocking enabling higher speed dynamos to be used. These engines are also entirely boxed in, the crank shaft and working parts running in oil. They are therefore capable of very long and continuous runs without requiring any attention when once the oil chamber has been filled up.

There is a prejudice, however, against this type of engine by many sea-going and other engineers, because they are not able to see what is going on inside the engine. This may or may not be a good objection, but there is no doubt that when a large amount of power is required in a small space, and where it is not possible to give any great attention to the engine, a single-acting engine of any of the three types mentioned above has given extremely satisfactory and economical results in working.

In steamships, where there is ample space for the machinery, vertical or horizontal engines, as found most convenient, arranged to drive with belts or ropes of reasonable centres, have been frequently used, and there is no doubt that, where there is sufficient room for the electric light engines and dynamos to be driven in this way, it forms a most convenient and reliable arrangement, because the engines are run at a moderate speed, reducing the amount of wear and tear to a minimum, and the dynamos are also run at speeds at which the greatest output can be got from them with the most economical results. Care must, however, be taken that the belts or ropes do not get saturated with either water or oil.

Having now given a general explanation of the construction of dynamos and of the various units in practical use, together with an explanation of the various systems of electric lighting, a brief description is given of a central station on the low tension three-wire system erected by the St. James and Pall Mall Electric Light Co. in London. (See Appendix A, page 297.) A description is also given of the Deptford station (see Appendix B, page 302) now in course of construction by the London Electric Supply Corporation, from which it will be seen that the experimental stage of electric lighting has long since been passed, and that electric engineering is taking a place beside some of the chief and heaviest branches of engineering.

APPENDIX A.

ELECTRIC LIGHTING IN LONDON.

The St. James and Pall Mall Electric Light Co., Ltd.

This company was formed for the purpose of supplying the electric light to the whole of the parish of St. James, Westminster. The first central station is situated in Mason's Yard, Duke Street, and consists of a building of three storeys constructed of white brick and fireproof throughout, standing in the centre of the yard and completely isolated from the surrounding buildings. The low tension direct-current system is used and the mains are laid on the three-wire system. Three mains start from the engine house, each of which soon bifurcates, and the six leads thus formed feed a continuous ring-main from which the outlying district is supplied. The points of junction (or feeder points) of the six leads with the ring-main are connected back to the engine house by pilot wires.

In cases where only a small number of lights is required a main is run along one side of a street only and connections taken off for the buildings on both sides, but where the demand is greater a main is run along each side of a street—examples of this may be noted in Pall Mall, St. James's Street, etc.—while buildings which lie within the ring-main are connected direct to one of the six leads. The mains are of ample size, and the maximum variation of potential is 2 volts either way. A loss of potential of 1 volt is allowed for in wiring the buildings, and by keeping lamps of three or four different voltages all parts of the district can be efficiently supplied.

The charge made by the company is 7d. per Board of Trade unit.

The whole plant is calculated to supply 20,000 lamps of 16 candle-power. Of this number it is safe to reckon that not more than 75 per cent. will be in use at a given time; it is therefore possible to wire 20,000 lamps and still work well under the total capacity of the plant.

Building.—The building measures 88 feet long by 21 feet broad, and three storeys in height. The engines, boilers, and dynamos are in the basement, which has been greatly enlarged by excavation under the yard. It is divided into two parts. The walls of the building are supported on girders carried by pillars and also upon buttresses, and an idea of

The basement is cooled by means of a Blackman air propeller, 6 feet diameter, driven by a high speed engine of 5 horse-power, the outer air being drawn into the engine house and caused to pass into the boiler house, and finding an exit by the bunker holes and windows.

Boiler House.—The boiler house is situated at the other end of the basement, and contains five boilers of the locomotive type, with space for a sixth. These boilers are among the largest of the type made. The dimensions are as follows:—External fire box, 6 feet $10\frac{1}{2}$ inches long by 6 feet $1\frac{1}{4}$ inches wide by 8 feet $2\frac{1}{8}$ inches high; internal fire box, 6 feet $1\frac{1}{4}$ inches long by 5 feet $4\frac{1}{8}$ inches wide by 5 feet 10 inches high; mean diameter of barrel, 6 feet; length of barrel, including smoke box, 13 feet $6\frac{1}{2}$ inches; total length of boiler, 20 feet 5 inches; tubes, 257, $2\frac{1}{4}$ inches diameter by 10 feet 11 inches long; shell plates, $\frac{5}{8}$ inch thick; internal fire box, $\frac{7}{16}$ inch plates for sides and crown, and $\frac{5}{8}$ inch plate for tube plate; heating surface in tubes, 1,593·4 square feet; heating surface in fire box, 146·8 square feet; grate area, 32·5 square feet. Riveting—longitudinal seams, treble riveted with double butt straps; circumferential seams, double riveted lap joint. Working pressure, 160 lbs. per square inch. They are built of the best mild steel.

The gases are delivered downwards into the cross flue below the floor level, which enters the base of the chimney near the feed-heaters. At one end of the house an artesian well has been sunk, which is lined with cast iron tubbing 5 feet diameter for 15 feet down, and then narrows to a wrought iron pipe of $11\frac{1}{2}$ inches internal diameter. The well is already sunk to a depth of 253 feet, and has reached the chalk. It will be worked by a deep-well pump, and the water raised into tanks which are built into the walls of the building on the third floor, and have a total capacity of 4,000 gallons, and from these tanks it will be drawn through the feed-water heaters, and fed into the boilers by two Worthington pumps with 4 inch rams, and one with $3\frac{1}{2}$ inch rams. All the boilers are also provided with injectors.

Steam and Exhaust Pipes.—The steam pipes are of wrought iron, 9 inches internal diameter and $\frac{3}{8}$ inch thick. They are all overhead, and are so duplicated as to prevent the possibility of a serious breakdown as the result of any single accident to the system of pipes.

There is a continuous 9 inch main supplying all the engines in pairs, and receiving steam from the boilers separately. Each boiler is designed to drive two engines. The various branch connections are made by such bends as to provide amply against the effects of expansion, and by means of eleven stop valves separating the different boilers and groups of engines,

The boiler house and two engine houses, now in course of construction, occupy a space 210 feet long by 190 feet wide and have a height from basement to roof of about 100 feet. The engine houses themselves are each 195 feet in length by 66 feet in breadth and 85 feet high, and are separated from the boiler house by a massive wall of masonry, a row of iron pillars separating the two engine houses, supporting the roof and the overhead travelling cranes which are required for lifting the heavy pieces of machinery about. The boiler house, which is entirely distinct from the engine house, is arranged in two floors, one above the other, the upper floors being supported on iron pillars, 30 feet high, with a coal store above capable of storing 4,000 tons of coal.

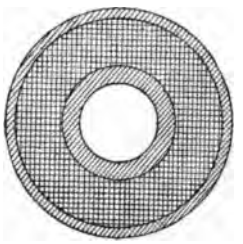
The coal will be unloaded straight from the wharf and hoisted to the top floor of the boiler house, from which it can be distributed by means of vertical shoots passing through the centre floors of the upper boiler house to the lower one. The two boiler houses are constructed to contain boilers of a total of 65,000 horse-power, but at the present time twenty-four boilers, equal to a total of 20,000 horse-power, of the Babcox and Wilcox type, are being installed. Economisers are placed at the base of the shaft so that the waste steam can be utilised for heating the feed-water.

There are two engines, each of 1,500 indicated horse-power, each driving a Ferranti dynamo for 25,000 lights of 8 candle-power by 40 cotton ropes. These dynamos will each be 12 feet 6 inches high by 15 feet long over-all. In addition to this there are to be three pairs of compound inverted cylinder engines of the marine type, each capable of working up to 10,000 indicated horse-power when running at a speed of 60 revolutions per minute. The dynamo is placed in between the two engines forming the pair, and to form an idea of the size of these dynamos it is sufficient to state that the armatures are 45 feet in diameter, and the total weight of each machine about 500 tons.

The whole of the dynamos are being constructed to work at an E.M.F. of 10,000 volts, and the current is being conveyed through the underground railway from Deptford to the city, where it is joined to distributing transformers reducing the pressure from 10,000 volts to 2,400 volts. From this distributing transformer overhead or underground cables, as found most convenient, are run in a net-work over the city, and the current is again transformed from an E.M.F. of 2,400 volts to an E.M.F. of 100 volts for the supply to houses, shops, and public buildings.

Mr. Ferranti has had some difficulty in the construction of his cables, and a brief description of the way in which they are made will probably be of interest.

The cables are concentric, as shown in illustration, that is to say, there is a copper conductor inside covered with insulating material surrounded by an outer conductor. For the construction of this cable special machinery has been erected at Deptford. The inner copper conductor consists of a copper tube of quarter square inch area, and is cut off in lengths of 20 feet, wrapped with brown paper, which is dried on a long hot plate and then passed through a cauldron of special black oil or wax which soaks into the paper, the copper tube being placed upon a trestle and slowly rotated, and the insulated paper wound on until the insulation is of a sufficient thickness. The outside copper tube is then slipped over this tube, being of the same sectional area as the smaller and thicker tube. The whole is then passed through a draw plate, and the outer tube drawn tightly over the insulation. The outside copper conductor is then insulated with waxed brown paper and taped; finally, a steel tube is placed over the outside for protection and hot wax forced in through a small hole by a force pump, driving out all air at both ends, and forming a compact and solid mass. These lengths of mains, as before stated, are 20 feet long, and are joined together in the following manner:—



SECTION OF THE FERRANTI CABLE.

The 20 foot lengths are put into a lathe and one end turned to a taper, 6 inches in length, the internal copper tube being bored out and about 18 inches of turned copper rod is placed into the tube, fitting tightly. The end of the next 20 foot length of conductor is bored out to a corresponding taper, the internal conductor being also bored to receive the copper rod. The two lengths of cable are then forced together, one cone fitting tightly into the other. They are then heated, which melts the wax and makes a perfect joint. A sleeve of thin copper tube is slipped over the lengths of cable before they are finally forced together, and is then brought back over the joint and corrugated with a special machine, which forms a metallic connection with the outer conductor. A further protection is provided by slipping a paper insulating sleeve over the top of the thin copper tube, and two steel sockets, similar to diminishing sockets, are then slipped over the outer steel

casing, which is filled in with bitumen, and the steel sockets are finally corrugated down upon the steel protecting tube, thus forming a compact and solid joint.

Owing to the high tension at which this system is worked there is, of course, a very great economy in the cost of the copper conductors; for instance, the conductors are about 2½ inches in diameter outside, the current density is 330 ampères per square inch, and one of these cables is capable of supplying 100,000 10 candle-power lamps with a loss of less than 3 per cent. These cables are tested whilst being laid by passing a current at an E.M.F. of 20,000 volts through them, and the writer believes are giving satisfaction. Of course it must be borne in mind that such an E.M.F. as 10,000 volts has never been previously attempted, and a distribution scheme at this high tension is necessarily an experiment until the little difficulties which may arise are overcome, but there appears to be no reason why they should not be satisfactorily coped with in time.

The Newcastle Central Stations.

In Newcastle two central stations have been started, one by the Newcastle and District Electric Lighting Co., Ld., and the other by the Newcastle Electric Supply Co., Ld. The former are lighting the left-hand side of Grainger Street, Nelson Street, part of Blackett Street, and Percy Street, with the whole of the district on that side from Barras Bridge; the latter are lighting the right-hand side of Grainger Street, Northumberland Street, Jesmond Road, and Jesmond, also Grey Street, and Dean Street. The former company has at present installed three Lancashire boilers, 28 feet long by 7 feet diameter, supplying steam to four Parsons's turbo-generators, each giving an output of 75,000 watts at an E.M.F. of 1,000 volts. The current is taken underground in cast iron pipes with junction boxes at intervals, and is tapped off where required into the consumers' houses. Two cables are used, run side by side in the pipes, highly insulated with india-rubber.

The latter company have installed three Lancashire boilers, 28 feet long by 7 feet diameter, two by Messrs. Robey & Co., of Lincoln, and one by Messrs. Hicks, Hargreaves, & Co., of Bolton. These boilers supply steam to three Robey compound engines, fitted with their patent trip cut-off gear, each engine being capable of working up to 250 indicated horse-power, and driving three alternating current dynamos by the Brush Company, each machine giving an output of 100,000 watts at an E.M.F. of 2,000 volts. In addition to the steam engines which

are used for the night service, a compound vertical engine to give 70 horse-power has recently been fixed for driving a 35,000 watt alternator for the day service. The cables in this installation are concentric and are run in cast iron pipes underground, with junction boxes, which are built of brick with cast iron covers. The current is then taken into the consumers' houses, and transformed in the ordinary manner.

DISCUSSION.

The VICE-PRESIDENT said the paper to which they had just listened was, in the history of the Institution, a new departure, introducing as it did, a subject which one might say, was still in its infancy. He did not know where he had seen it, but it occurred to him he had heard it said "that electrical engineers ought to be three-fourths mechanical engineers," and presumably, mechanical engineers would be all the better of being one-fourth electrical engineers. From this point of view the paper would be very valuable indeed. A great deal of the paper being explanatory and descriptive it did not readily lend itself to discussion, but he presumed the subject could not be absolutely clear to everyone of them, and Mr. Mountain would be very glad to answer any questions and to deal with any discussion on the subject.

Mr. JAS. THOMSON, Jun., wished that the discussion had been opened by an electrical engineer, seeing that the paper contained a great deal that he did not feel himself competent to speak about. He had been very much interested in hearing it, however, and saw a great deal in it to read over again. He would only speak about one matter which he did know something about, that was the question of wiring ships with a single or a double wire. The author of the paper described the two methods, but did not show a decided preference for either the one or the other. To his (Mr. Thomson's) mind, there were two very strong reasons for preferring the double wire installation; one of these was indicated in the paper, viz.:—the liability to bad contacts and fire on board ship. The other was the danger of producing an error in the compass. In the installation with a single wire, one wire was led from the dynamo and branches taken from it to the different lamps; a return wire from each lamp was connected to some portion of the hull of the ship, and the negative pole of the dynamo also connected with the hull of the ship, the return current thus went through the shell plating of the ship. Now, so far as he knew, those connections were generally made by getting the wire screwed in under the nut of a deck bolt, or some nut

screwed against a beam. Well, beams were always painted or red leaded before the wires were laid, and there was a great liability of the contact being bad; if not bad to begin with, it would become bad afterwards. There was then danger of sparks passing, and setting the wood work on fire. Then, in addition to that danger, which was referred to in the paper, there was the liability in the single wire system of the current affecting the compass. This subject was very important. It was well known that if a wire conveying an electric current ran parallel to a magnetic needle, the current passing tended to make the needle set itself perpendicular to the current. Supposing a main wire for lighting a ship ran fore and aft, and supposing the ship was sailing northward along the magnetic north, the current, being then parallel to the needle, the tendency would be to turn the needle at right angles, that is, athwart the ship. When a single wire conveyed a current in the neighbourhood of the needle, it would tend to deflect it; but if the ship was wired with double wires laid alongside of one another, the two currents to and from the lamps would neutralise each other, and the effect upon the compass would be *nil*. If the ship was lighted with an alternating current there could be no effect on the compass; but with a continuous current and the single wire system the needle might be affected to a considerable extent. He had got from his friend, Mr. Bottomley, a formula by which the amount of the deflection could be calculated :—$E = \frac{\cdot 2C}{H \times D} \times 57 \cdot 3$. E being the error in degrees, C the current in ampères, H the earth's horizontal force at the place, and D the distance in centimetres from the wire to the needle. Of course, he should say that the effect on the compass depended entirely upon the course the ship was steering, because the current tended to set the needle perpendicular to the wire carrying the current. If the ship was on such a course that the needle was already at right angles to the wire, the effect was nothing. The formula gave the greatest effect possible. Mr. Bottomley, who gave him the formula, had had opportunities of observing their effect in several ships, and in a paper read by him before the Society of Arts on "Magnetism of Ships," he said :—"Take as an example, a main laid from the dynamo machine to light up a saloon with one hundred lamps or more. It may run along nearly underneath the position of the standard compass. The current may be taken at 100 ampères. In such a condition of affairs the error produced on the compass will amount to as much as 7½ degrees when the wire is at a distance of 30 feet. Now, this error will only be produced at

the time when the current is flowing to light up the lamps, and it may never be detected by the officers of the ship." He did not know how close a captain was ordinarily able to steer his ship, but he thought an error of $7\frac{1}{2}$ degrees very serious. He had heard of a case of 9 degrees error in the compass from this cause. The captain, of course, frequently checked his compass at sea by taking observations, but he usually did so through the day when the lights were off. The ship might then be steered for several hours at night 7 or 8 degrees off her true course. That was a serious matter, which, he thought, ought to be attended to. It would be entirely got over by using the double wire, and the extra cost was as nothing in comparison with the advantage to be derived. He (Mr. Thomson) saw nothing in favour of the single wire but its cheapness. This matter only came in incidentally in the paper, which altogether was an important contribution on the general subject of electric lighting. They were much indebted to Mr. Mountain for bringing it forward. Before sitting down he might just mention that one firm of shipbuilders on the Clyde, who did their own electric lighting, preferred lighting with single wires mainly on account of economy; but in designing the arrangements they always worked out by the formula given, the effect on the compass, and if they found the error would be appreciable, laid double wires, and by this means prevented any error to the compass arising from the electric light installation.

Mr. J. H. HOLMES said the paper they had just listened to did not lend itself very well to discussion (as their Vice-President remarked), as there was little in it open to controversy or likely to bring out a difference of opinion. The paper seemed to him to be a clear statement of some of the first principles of electrical engineering, more especially with reference to electric lighting, and ought to be regarded by young members of that Institution as a reliable guide to their studies. He thought they had before them a very good and interesting paper, it covered a great deal of ground and must have given the author a considerable amount of trouble. Passing to the point in the paper which Mr. Thomson had mentioned as the only one which he thought was open for discussion, the question of single and double wiring in steamships, he might say that since his firm lighted the S.S. "Nonpareil," which he thought was the first Tyne-built vessel lighted with electricity, they had fitted 150 vessels with their apparatus, including such important ships as the "City of Paris" and the "City of New York," and scarcely a dozen of that number were fitted with the double wire system. The consensus of opinion was that the single wire

system had a great advantage on account of its simplicity and freedom from short circuit and leakage. The experience of those firms longest in the business, and of those that had carried out the largest number of installations, such as Messrs. Siemens Bros. & Co., and The Brush Co., was to the same effect in regard to single wiring. The P. and O. Co., the British India Steamship Co., the Union Steamship Co., and others, declared that it gave the greatest satisfaction, and Mr. Liste, of Messrs. Donald Currie & Co., told him the other day that their nine steamers were lighted on the single wire system, and that they would not on any account change to the double wire system. Mr. Thomson had drawn attention to one or two points which he would wish now to take up. He was afraid Mr. Thomson spoke more from hearsay than from actual experience, when he talked of the connection to the deck frame of the ship. It was not usual to put the wire under the nearest bolt. The way with single wire firms was to drill and tap a hole specially, and attach the wire and make an electrical connection by means of a brass screw and a brass washer, and if that was screwed up tight there was not the slightest chance of it going wrong any more than the other electrical connections. There were hundreds of connections of the same kind in an installation, such as those in switches and fuses. He did not see why one in the body of the ship should be more liable to go wrong than any other connection. With regard to the effect upon the compass, that was an extremely important matter, but he would point out that in the formula given by Mr. Thomson no account was taken of the screening action of the iron decks. If a wire was run under an iron deck the iron practically screened the compass from the deflection that would otherwise be caused by the current running in the wire. He thought Mr. Thomson mentioned that he had heard of an error of 9 degrees, due, as he put it, to the use of the single wire system; but he (Mr. Holmes) believed that error was not due to that at all, if the case was the same as he had in mind. It was on an Admiralty vessel, fitted on the double wire system, and the error was due not to the current on the cables, but leakage from the dynamo magnet; that was the source of error in the compass.

Mr. THOMSON—There is more than one such case.

Mr. HOLMES—He was not alone, as he had mentioned, in advocating the single wire system, and he would like just to read what was stated by Mr. Siemens, for instance, he said: "that his firm had lighted a large number of vessels and with one exception there had never been

any effect produced on the compass, and that was one in which the compass was put up after the electric light, and it was, by mistake, put too near to the wire. They offered to remedy this at once, as it only required a return wire alongside the leading wire, but the captain said he was quite satisfied, as on swinging the ship he had made careful observations with the light on and off, and he knew what the compass would do, and did not want his cabins pulled about. He added that the iron of the ship had always been found an effective screen, if between the wire and the compass." Mr. Hall, of the P. and O. Co., said that "some fears had arisen in the minds of the nautical staff that the compass would be affected by taking the current through the ship; but after careful and prolonged observation it had been proved that such fears were groundless. He also stated that his company had only one of their fleet double wired, and that in this vessel they had had most trouble from corrosion of the wires." Prof. Jamieson, after reading a paper on the "Electric Lighting of Steamships" before the Institution of Civil Engineers, summed up the whole of the matter, after a very full discussion, by saying that "the single wire system was the cheapest, simplest, and best on board ship." Commander Creak, R.N., said that "in the 'Polyphemus' the single wire was adopted, and the hull used as the return, and experiments in her proved that no deflection of the compass was caused." Sir Wm. Thomson was, no doubt, a great authority on such matters, and he believed, had stated that double wiring was the best; but Sir Wm. Thomson, though of a practical turn of mind in some ways, was not always so, and had designed some of the most extraordinary dynamos, dynamos which had not yet been, and probably never would be, made, and so they could not look upon him as practical in all things. He, however, in regard to compass deflections, urges careful testing and says, that "the test should be made when the vessel is in dock or lying steadily at anchor. A sufficient practical test may be made by first observing the effect of starting and stopping the current on the compass as it stands; then adjusting a small magnet placed on, or supported a little above, the glass of the bowl, to deflect the compass about 45 degs. first on one side and then on the other side of its undisturbed position, and in each case observing the effect of starting and stopping the electric current. This effect ought not to be as much as 2 degs. in either of the three cases." He thought they ought all to feel indebted to Mr. Mountain for bringing this subject forward, and it was quite evident he must have put himself to no small amount of trouble not only in the production of the paper but likewise in the illustrations.

Mr. HARRY GRAY said the paper would prove of great benefit, especially to those who had not had the training of electrical engineers. It had been his privilege to hear a good deal about concentric wiring, and it was upon that point he would like to offer a few remarks. Mr. Mountain had said that the objection to this class of cable was that it was more difficult to joint than two ordinary cables. He would like to show Mr. J. D. F. Andrews's mode of jointing for this kind of wiring. (Plate XXXIX.) In making the joint Mr. Andrews removed the outside armouring for a few inches; that took the return current; then he tapered down the insulation, leaving the centre conductor exposed; round this the centre conductor of the branch wire, which had been already prepared in a similar way, was secured, and it was then covered with the insulation —first, a layer of pure rubber; then a mixture of rubber and soapstone, known as the separator; and then a layer of rubber containing a large proportion of sulphur; over this is wrapped a piece of prepared cotton cloth. To make good the outer conductor where the outside armouring has been removed, a copper sheath is wrapped round, thereby ensuring the continuity of the return conductor. In a T-joint the one sheath projects slightly through the other one. Then a cast iron mould is placed round the joint, and by an arrangement of "gates" in the mould the joint can be run in any position, molten metal being poured in, the temperature of the melting point of which being such as to vulcanise the outer insulation of rubber. Two joints are shown in section on the diagram (Plate XXXIX.), a T-joint just described and also a union joint of two wires, a copper sheath being soldered over the two ends of the centre conductor. The construction of a "switch" and also of a "fitting" is shown, all the contacts of the fitting are insulated with soapstone composition, contact with the terminals of the centre conductor being made by brass springs soldered on to the opposite centre conductor in the usual way, which are compressed in contact against the end of the terminals of the other wire when the fittings are screwed together. The centre conductor through the fittings is insulated with india-rubber. One of the great advantages of this class of wiring is the reduction of the fire risks. The case which was given in a paper read by Mr. J. D. F. Andrews before the Philosophical Society of Glasgow, in 1889, viz., that of an Atlantic liner in which the wood casing becoming saturated for about 8 feet the insulation was destroyed in consequence; the electric current took a diagonal course across with the grain of the wood from one wire to the other, charring it for about 18 inches; fortunately it was discovered before serious damage was done. With concentric wiring this would have been impossible, the only leakage possible would be a

dead-short circuit from the centre conductor to the outer or return conductor, which, as it does not pass any inflammable material, would reduce the probability of any fire arising from it, and such fault would be betrayed by the fuse and the other ordinary precautions. A few specimens of joints and fittings were on the table, kindly lent by Mr. J. D. F. Andrews. The mechanism of the switch consisted of a cam, which is acted upon by a pin in the handle, thereby compressing the spring under the contact disc, which is thus brought in contact with the terminals of the centre conductor; upon a quarter of a turn of the handle a sudden break of the contact takes place by the action of the spring under the contact disc. The contact disc is insulated from the cam, etc., by a disc of soapstone composition. In making contact a rubbing action takes place between the contact disc and the terminals of the centre conductor, removing any dust or moisture.

Mr. EUGENE BROWN said Mr. Mountain had given the comparative efficiencies of the high tension alternating current, and the low tension continuous current, and had shown the difference to be 30 per cent. He might point out that the case taken for the continuous current was one not likely to occur in practice; no electrical engineer would design an installation on those lines. Each ought to be taken on its own merits. The alternating current was taken with full load, with decreased load the efficiency diminished enormously, though he did not think that any central station could at any time show an efficiency of 98 per cent. Sometimes the efficiency of transformers was as low as 50 per cent., which would bring the efficiency of 98 per cent. to even below the efficiency of the continuous current system; also, that whereas the transformer system showed diminished efficiency with less than full load, the continuous current system *increased* in efficiency when the load was decreased. Even taking the comparative statement of the St. James's Company made in the Appendix, where the three-wire system was used with continuous current low tension, there the efficiency was brought out at 98 per cent., and he thought that bore a very good comparison with the high tension alternating current; but, of course, there were cases when the high tension alternating current had decidedly the advantage, and not at all to be disparaged. Mr. Crompton had shown in one of the districts of London that a great deal could be done over large areas with the continuous current, but the figures in the paper seemed very strongly against it.

Mr. J. F. WALLIKER said that he had not come to the meeting with the intention of speaking, as he was quite a student in the matter of electrical engineering. However, as the discussion that night had rather

hinged upon what had been a puzzle to most of them, viz., the merits of the single wire system as compared with the double wire system, perhaps the result of the testing of one of the former on a recent trial trip might be interesting. This was a large vessel fitted up by a first-class firm, and on the trial of the installation at sea there was found a difference in the standard compass between dynamo on and off of 4 degs., the nearest single or trunk wire in this case being 11 feet distant. At the steering compass, where one wire ran within only 4 feet and with only a wooden deck between, there was found the enormous deflection of 19 degs. This wire ran from port to starboard, and there was no variation found on the north and south courses. With regard to the case quoted by Mr. Siemens, the man at the wheel, even although he might be fully informed about the difference to be expected when the dynamo was on and when the dynamo was off, might not always be aware of the fact or at any rate know the number of lamps in use, which he believed would affect the strength of the current. He might add this, that Lloyd's Registry had issued some suggestions for guidance in electric light installations on board ship, and it would be noted that only those vessels fitted on the single wire system were required to be tried for compass variations. He did not know whether that was anything serious to be deduced against single wiring, still he thought it was a fact worth mentioning that there was a danger in one instance which was absent in another. He might add that in single-wired ships it was the practice to fit double wires in proximity to the compass, but still the main wires had to be carried forward, and in some cases these had been found to be too close to the binnacle and altered after trial. He thought the Institution ought to be extremely grateful to Mr. Mountain for his very able paper, and the general interest in it was evinced by the large attendance there that night.

The VICE-PRESIDENT said if those present had no further remarks to make he would adjourn the discussion to the next meeting. He was quite certain he only expressed the feelings of all present when he said how very much indebted they were to Mr. Mountain, not only for his paper, but for the preparation of these elaborate diagrams and the exhibition of the numerous specimens on the tables and also out in the hall. Although there had been a good deal of discussion that night, he thought there would very likely be more at the next meeting, which would be resumed at Sunderland, on Friday, 10th April, when, after the discussion was finished and Mr. Mountain had replied, Mr. Hök's second paper would be taken.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890–91.

PROCEEDINGS.

NINTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE SUBSCRIPTION LITERARY SOCIETY, SUNDERLAND, ON FRIDAY EVENING, APRIL 10TH, 1891.

W. THEODORE DOXFORD, ESQ., PAST-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Newcastle, on March 23rd, which were approved by the members present, and signed by the Past-President.

The ballot for new members having been taken, the Past-President appointed Messrs. J. R. Fothergill and H. Macoll to examine the voting papers, and the following gentlemen were declared elected:—

MEMBERS.

Baguley, Ernest Edwin, Engine Draughtsman, Messrs. R. & W. Hawthorn, Leslie, & Co., Forth Banks; 3, Saville Place, Newcastle-on-Tyne.

Cameron, David. Engine Draughtsman, Messrs. Gourlay Bros. & Co., Dundee; 18, Arbroath Road, Dundee.

Jackson, William S., Chief Ship Draughtsman, Messrs. Gourlay Bros. & Co., Camperdown Shipyard, Dundee.

List, John, Superintendent Engineer, Messrs. D. Currie & Co., Orchard House Works, Blackwall, London, E.

Nunes, Enrique E., Engineer, Argentine Navy, Elswick Shipyard, Newcastle-on-Tyne.

Tinkler, Robert Harrison, Engine Draughtsman, Messrs. Clarke, Chapman, & Co., Gateshead-on-Tyne; 44, Blyth Terrace, Gateshead-on-Tyne.

Wallis, Robert, Engine Draughtsman, Messrs. Wallsend Slipway Co.; 75, Heaton Park Road, Heaton, Newcastle-on-Tyne.

GRADUATES.

Clague, James Henry, Ship Draughtsman, Messrs. Laird Bros., Birkenhead Iron Works, Birkenhead.

Gibson, Joseph H., Engine Draughtsman, Messrs. Laird Bros., Birkenhead; 8, Coltart Road, Prince's Park, Liverpool.

Wedgwood, Josiah Clement, Apprentice Shipbuilder, 7, Sydenham Terrace, Newcastle-on-Tyne.

Weinberg, Herbert James, Apprentice Engineer, Messrs. Gourlay Bros. & Co., Dundee; Fernbrae, Dundee.

NOMINATIONS FOR THE COUNCIL.

The PAST-PRESIDENT announced that, in accordance with Article X. of the Constitution, the following gentlemen retire from the Council:—President — Mr. Wigham Richardson; Vice-Presidents — Messrs. H. Macoll, P. Watts, and R. L. Weighton; Hon. Treasurer—Mr. B. G. Nichol; Councilmen—Messrs. J. R. Fothergill, T. Millar, James Patterson, John Price, and A. Scholefield.

In accordance with Bye-Law 11, the Past-President, on behalf of the Council, nominated the following gentlemen to be balloted for to fill up the vacancies:—President—Mr. Wigham Richardson; Vice-Presidents (three to be elected)—Messrs. J. R. Fothergill, James Patterson, John Price, H. F. Swan, and J. Tweedy; Hon. Treasurer—Mr. B. G. Nichol; Councilmen (five to be elected)—Messrs. W. Hök, G. E. Macarthy, H. Macoll, D. B. Morison, J. W. Reed, R. L. Weighton, and P. D. Winstanley.

Mr. M. SANDISON nominated Mr. W. C. Reynolds as a member of the Council.

Mr. L. NEWITT nominated Mr. M. Sandison as a member of the Council.

The PAST-PRESIDENT gave notice that at the Closing Business Meeting, to be held in Newcastle-upon-Tyne, on May 11th, the President, on behalf of the Council, would move that the following alterations be made in the Articles of Constitution and the Bye-Laws:—

NOTE.—*Proposed alterations are in italics.*

CONSTITUTION.

X.—Paragraph 3 to read as follows:—

The retiring Vice-Presidents *shall be eligible for re-election.* The retiring Councilmen shall not be eligible for re-election to the same offices until after an interval of one year, but shall be eligible for election to any other office.

BYE-LAWS.

31.—The following Sub-Committees shall be appointed annually *at the first meeting* of the Council *in each Session:*—(1) A Finance Committee, to consist of seven persons, viz., one Past-President or Vice-President, who shall be chairman; five Councilmen, and the Honorary Treasurer of the Institution; three of whom shall form a quorum. The Treasurer shall be empowered to pay all amounts due from the Institution which are under two pounds. All amounts of two pounds and upwards shall be paid by cheque signed by the chairman of the Finance Committee (or in his absence, by the President or a Past-President), the Secretary, and the Honorary Treasurer. (2) A Reading Committee, to consist of six members of Council. *No member who has served on this Committee for three years in succession shall be eligible for re-election until after an interval of one year.* (3) *A Library Committee, in accordance with Library Bye-Laws Nos. 1 and 3.*

35.—Old rule to be rescinded and the following to be inserted:—*The Secretary shall send to each speaker as soon as possible after a General Meeting a copy in manuscript of the speaker's own remarks for correction. This copy must be returned to the Secretary within four days. A printed proof will also be sent to each speaker for further revision; this must be returned to the Secretary within three days, otherwise it will be deemed correct, and printed off after receiving verbal corrections.*

36.—Add after the word "Secretary" *and must be approved by the Reading Committee.*

New Bye-Law to be numbered 44:—

The capital, stock, and funds of this Institution shall be vested in the names of three Trustees to be elected from time to time as vacancies occur by the members of the Institution at a General Meeting called for that purpose. All mortgages and other securities shall be taken in the names of such Trustees; and on any new appointment the funds shall vest in the newly-appointed Trustee or Trustees jointly with the continuing or remaining Trustee or Trustees.

The present Bye-Law No. 44 shall be numbered 45.

The discussion on Mr. W. C. Mountain's paper on "Electrical Engineering" was resumed and closed.

Mr. W. Hök then read his second paper on "The Unsinkability of Cargo-Carrying Vessels;" the discussion was opened and adjourned.

ADJOURNED DISCUSSION ON MR. W. C. MOUNTAIN'S PAPER ON "ELECTRICAL ENGINEERING, WITH SPECIAL REFERENCE TO ELECTRIC LIGHTING."

Mr. M. SANDISON, in resuming the discussion on the above subject, said there was one point in connection with Mr. Mountain's comprehensive paper that he should like to know more about. In Appendix A (page 297) he told them, when describing the central station of the St. James's and Pall Mall Electric Light Company, that the steam pipes were of wrought iron, 9 inches internal diameter, $\frac{3}{8}$ inch thick, and working at 150 lbs. pressure. It would, he thought, be of interest to the Institution were Mr. Mountain to give them some information as to the construction of these pipes: how the flanges were secured, and whether they were giving satisfaction. In marked contrast to that arrangement, in Appendix B (page 302), when describing the Deptford central station, Mr. Mountain had omitted to direct their attention to the multiple copper steam pipe introduced by Mr. Ferranti. This was the direct outcome of the mishap at these works in 1889. In place of one pipe, 9 inches diameter, he utilised seven solid drawn copper pipes, some $3\frac{1}{4}$ inches in diameter, with the ends expanded into a common flange. It would be interesting to know if this system was also giving satisfaction. He could not say that he (Mr. Sandison) thought it a step in the right direction. Both of these departures from the usual practice of fitting a brazed copper pipe served to emphasise the opinion expressed in a paper on "Main Steam Pipes" which he had read before the Institution a few months ago, viz., that the subject was, to say the least of it, in a somewhat unsettled state.

Mr. L. NEWITT said he was unable to be present at the previous meeting, but understood that the electric lighting of ships was the great point under discussion, and that single wiring had been advocated. Having lighted a great number of vessels, he ventured to give his opinion with reference to the wiring, which was, that where the electric light was put into a ship it should most certainly be on the double wire in preference to the single wire system. His reasons for arriving at this conclusion were: that in the double wire system, if they by chance got a leak on one wire the installation would not break down, whereas in the single wire system if they got a leak on a wire the whole circuit would probably be useless

until the leak was found and remedied. This was very important, because at the present time very few ships carried an engineer qualified to deal with such matters, and so a part or the whole of the ship might be thrown into darkness for the greater part of a voyage. With a double wire system there was only half this chance of a breakdown. The question of making a safe connection on the hull of the ship for the return instead of using another wire introduced a weak point. Unless a very expensive earth connection was made, which gripped the insulation of the cable and made it water-tight, the system would last comparatively no time. If there was any bare copper exposed, the salt water or spray would attack it, and in a very little time considerably reduce the sectional area of the wire, then the current would cause heating, and if eaten away to any extent, the wire would become very hot, and might set fire to any inflammable material in its neighbourhood. If it did not cause a fire, the wire conductor would simply burn up, and the light depending on this wire would go out. Again, the current in a single wire system played a very important part in its effect upon the compass. It is found by calculation, that a compass would not be affected in an ordinary sized ship if her decks and hull were of iron some 3 feet thick, and all wires kept below. But this design of ship is impossible; so it is found that some of our ships, electrically lighted on the single wire system, show in many cases a disturbance of the compass of from 3 degs. to 7 degs., when groups of lights, in various parts of the ship, are thrown on and off, as is customary in ordinary sea-going passenger ships. To prove this, he had made some experiments a few days previously on board a cruiser to see what effect they could get from screening the compasses; and having two compasses exposed he tried to see what the result would be with a current of 100 ampères, which is the current required for about 120 lamps. Using Sir Wm. Thomson's compasses with six needles, he placed a single wire 3 feet from the compasses, on a level with them and in a horizontal direction, and got a deflection of 58 degs. Next, he fixed the wire 6 feet in front of the compasses, the wire passing down vertically, and got a deflection of 10 degs. He then took the wire 14 feet away, over the side of the ship, the wire running fore and aft, and got 8 degs. deflection; and at 20 feet away it was $7\frac{1}{2}$ degs. In these two cases the iron intervening between the compass and the wire was $\frac{1}{4}$ inch and $\frac{3}{8}$ inch thick, thus showing that the iron plating on the side of the ship had very little screening effect upon the compass. Next, he passed the same wire directly under the compass, running fore and aft, the deck between being partly iron and partly wood, and at a distance of 12 feet the deflection

was 12 degs. He carried it 20 feet away, under an armoured deck, varying from 1 inch to 2½ inches in thickness, and practically without any openings, and got a deflection of from 2 to 2½ degs. At a distance of 10 feet, the compasses being in a conning tower, the mean diameter of which was 7 feet, and whose sides were 4 inches thick, with two iron floors each ⅜ inch thick, and a roof ¾ inch thick, there was still a deflection of from 2 to 2½ degs. These last two experiments went to prove that the effect of the current upon the compasses decreased with the thickness of the intervening plate. But, small as these deflections were, 2 degs. were equal to 35 miles per 1,000, or in a voyage, say from Queenstown to New York, an error of 105 miles; and a deflection of 2½ degs. would give an error in the reckoning of 44 miles per 1,000, or on the same voyage an error of 132 miles. They might say that this would be impossible as they would be taking their bearings, but it was possible to imagine cases in which cloud or fog prevailed for several days, when it would be impossible to take bearings. In cases of this kind an error of 2 degs. might be attended with very serious consequences. The above results were generally checked by two compasses, so that the results were fairly accurate. Summing up these points, then, these were his conclusions:—

(1) In the single wire system there is twice the chance of a breakdown.

(2) More danger of fire through bad contact with the ship and exposed wire eaten away by the salt water.

(3) The serious effect upon the compass, which it is impossible to screen efficiently.

When these facts became known to shipowners single wiring would never again be admitted at sea, especially when it could be avoided in an ordinary sized ship at an extra cost of about £60. That finished all he had to say on ship lighting. He wished now to deal with a point on page 275. Mr Mountain stated there that "the advantages of increasing the number of poles in dynamos of large capacity, consisted in the increased ventilation in the armature due to the larger diameter and consequently increased surface." A well-designed machine should not require ventilation, as there should not be heating. Any generation of heat meant loss of power, and therefore less economy. He had seen two-pole machines running 600 lamps, and no unusual heating had occurred. Their efficiencies had also been very high, therefore he should like to know for what number of lamps the writer advised the use of an increased number of poles? It was natural to sup-

pose that machines having more than two poles, were more expensive than two-pole dynamos, and more complicated and difficult to keep in order, so he (Mr. Newitt) thought two-pole machines should be used up to 600 lamps or more. On page 278, the writer said that "a shunt wound dynamo is not suited for running incandescent lamps, unless a variable resistance is placed in the field magnet circuit." He (Mr. Newitt) thought it was found in practice, when the engine was electrically governed, that shunt wound machines worked perfectly. Take the case of the Parsons's turbo-electric generator. This machine was shunt wound, but owing to its electrical governor the voltage was quite constant. He had fitted more than twenty of these machines into ships of war, and on the trial of the machines it was found that at full load they gave 80 volts, and when the whole load was suddenly thrown off the voltage did not rise to more than 82 or 83 volts. Thus, here was a case where he had often seen shunt wound dynamos work perfectly in combination with an electrical governor on an incandescent electric light circuit. This arrangement enabled them to charge accumulators with safety; therefore this combination became very important. On page 281, the bottom paragraph but one, the writer says: "The fire insurance companies have now issued rules in which they state that a density not exceeding 1,000 ampères per square inch section of copper in the conductors is permissible." For installations of any great size this was found too high, as it caused too great a drop in volts to be satisfactory. He (Mr. Newitt) found that it was best to wire large installations on a basis of 600 to 800 ampères. He should like to hear what Mr. Mountain had to say on that point. On page 282, the first line after the tabular matter, would, he thought, more correctly read: "An ordinary 16 candle-power 100 volt incandescent lamp requires '65' watts to feed it," instead of 60 watts. This point is of importance when the power of a large installation is being arranged. For example, in an installation of 600 16 candle-power lamps this alteration would require an additional allowance of 4 horse-power. On page 287, mention was made of various accumulators, but there were several modern accumulators not mentioned. For example, the Crompton-Howell accumulator, now in extensive use at the stations of the Westminster Company and of the Kensington and Knightsbridge Company. Then, there were the new cells of Drake and Gorham and Johnson and Phillips. Both of these new cells were of the Planté type, and seemed to have great advantages over others at present in use. He would be glad if Mr. Mountain would give them some information on these. He thought the efficiency for high tension currents quoted at 98 per cent. on page 290 was rather

high. A transformer often ran with very light loads, and then the efficiency was reduced to 60 or 70 per cent. Taking the mean efficiency of a transformer at full load and light load it would not be more than 80 per cent. Then, the leakage and other losses must be taken into account; so that the 92 per cent. seemed high. He had had very little experience with high tension currents, but he mentioned this point because he often noticed that comparisons were made in favour of high, rather than low tension. He was glad to see the writer had mentioned the question (page 294) of placing of dynamos in a ship. It was exceedingly important that dynamos should be in a clean, dry, spacious room, away from the main engines of a ship, and, wherever possible, sight feed lubricators should be used, so that the bearings would get sufficient oil, but not too much, or the armature would draw in the oil and become saturated. On page 295 friction and belt gearing were mentioned. As far as his experience went he found that they should be avoided wherever possible, and direct-acting machinery used instead. The slip on belts was proportional to the load, and as the load was constantly varying the machine would vary in speed, and consequently a rise in voltage, so that at one time the light would be too bright and at another not bright enough. Direct-acting machines took up less room, and in many cases were lighter, and would run for longer periods without attention.

Mr. B. G. NICHOL said that the present system of electric lighting was a comparatively modern development of mechanical engineering science, the knowledge of which was mainly confined to the manufacturers of electrical machinery and to scientific experts. The present discussion might be instanced as a case in point, for each speaker, up to the present, was either a manufacturer of electrical machinery or engaged in making electric installations. Although the trained electrician might be disposed to treat as elementary information a great portion of Mr. Mountain's paper, yet it appeared to him (Mr. Nichol) that the paper would be a great boon to the attendants in whose charge electric light installations were usually placed, who, in many cases, had a very limited knowledge, and in perhaps the majority of cases no knowledge at all, of electrical science. Mr. Mountain evidently recognised that the attendants and users of electric lighting appliances, as also many of our members who have had no opportunity of studying electric lighting, should know something of the structure of the machinery, of the manner in which electricity was generated and applied, that is, the manner in which electrical energy was converted into light, and this he (Mr. Nichol) considered greatly enhanced

the value of the paper. He did not wish to make any lengthy remarks, as the previous speaker (Mr. Newitt) had practically exhausted the arguments raised on the points discussed. The practical outcome of the discussion, it seemed to him, was whether they were to have double or single wires in any case of electric light installation. He, for one, having had some experience, not so much in electrical engineering as in other spheres of electrical work, distinctly stated that in no case would he adopt the single wire. For safety and endurance he was of opinion that in the electric lighting of ships the complete circuit was necessary. He would not indeed have the single wire system either afloat or ashore. Some of those who had had practical experience in the working and maintenance of installations might, he thought, supplement what had been said with some useful information.

Mr. G. N. Arnison, Jun., remarking that he was not an electrical engineer, recalled the circumstance, ten years ago, when he was representing the owners of a large steamship, in which they had had fitted a very large installation. It was on the single wire system, and he remembered very well that there was considerable difficulty with it. For instance, a fire occurred in the ceiling of one of the deck cabins just after it had been beautifully finished and decorated. Another time, in a large saloon, with accommodation for about 300 people, there were about 100 guests seated at dinner when the light went out, and there was no alternative but to resort again to the primitive candle light. Although amusing in one sense, it was rather annoying, too, and his belief was that the *contre-temps* was due to the inefficient single wire system. From all he had since seen he quite agreed that the double wiring was preferable on board ship.

Mr. Wm. Morrison thought that the writer's remarks on the fire insurance rule, which states that a current density of 1,000 ampères per square inch is permissible, and which, the writer says, "is found to be an extremely satisfactory one, at any rate for small conductors carrying up to 100 or 200 lamps," must refer to the case of ship lighting, where the dynamo is in the midst of the lamps, for when the distance from the dynamo to the lamps was considerable, a current density of 1,000 ampères was not at all desirable. He (Mr. Morrison) was of opinion this was better brought out in Appendix B, at the Deptford central station, where the writer gives the current density as 330 ampères per square inch, and one of these cables was capable of supplying 100,000 ten candle-power lamps with a loss of less than three per cent. When the resistance was great the loss of power was proportionately great, and the loss on a current

density of 1,000 ampères being considerable, it became a matter of importance in large installations to fix on a suitable current density; in fact, he might say, that for each installation there was a particular current density which was most suitable for that installation. In the case of ship lighting, he thought that an occasional density of 1,000 ampères was not at all unreasonable or too much, but certainly not to exceed 1,000 ampères. The heat developed in a wire by a current having a density of 1,000 ampères was not very great; in a bare conductor of pure copper, having a conductivity of 96 per cent., a current of 100 ampères would give a rise of temperature of about 22 degs. Fah.; the rise of temperature for a current of ten ampères under the same conditions being about 7 degs. Fah. He thought with regard to the single and double wire systems of ship electric lighting that as far as he had seen the double wire was certainly the better of the two, for in it there was less liability to a breakdown of part or of the whole circuit from the causes already mentioned.

MR. MOUNTAIN'S REPLY.

Mr. MOUNTAIN, in reply to the discussion, said he regretted that the paper which he had written had not lent itself to more discussion, but being the first paper on electric lighting that had been read before this Institution he felt that it would be best to read such a general paper as would convey as much information as possible to all classes of members. At the same time he hoped that, having led up to the parallel and alternating systems of distributing, and having given a general description of the single and double wire systems of ship lighting and the different classes of engines used for installations on board ship, there would have been sufficient basis for a more lengthy discussion than there had been. Mr. James Thomson in his remarks touched upon two very important matters, namely, the relative advantages of the double and the single wire system and the effect of the single wire system upon the compass. As Mr. Holmes also expressed some opinions on the single and double wire system, he would give what information he could respecting the effect of the single wire system on the compass, and then reply to both Mr. Thomson's and Mr. Holmes's remarks on the relative advantages and disadvantages of the two systems. He had not until the last meeting seen the formula which Mr. Thomson stated had been used for calculating the amount of deflection due to a current of electricity passing a compass. Such a formula must be extremely valuable, but he was afraid that it was hardly capable of universal application, because there were very few positions in a ship

where there was not a certain amount of iron, and the iron in the beams themselves would be sufficient to upset this formula, even supposing the deck was entirely of wood. At the same time he thought that anybody working by the formula, and not taking into account any iron that might be within a small distance of the cable would be on the safe side. Since the reading of his paper he had tried some experiments to ascertain the actual deflection upon the compass, and had made in all eight tests as follows:—*Double wire system.*—No. 1.—Cables 7 feet from compass, below deck, with a current of 30 ampères flowing; no deflection. No. 2. —Cables 7 feet from compass, above deck, with a current of 30 ampères flowing; no deflection. No. 3.—Cables 7 feet from compass, above deck, with a current of 80 ampères flowing; no deflection. No. 4.—Cables 2 feet from compass, above deck, with a current of 80 ampères flowing; no deflection. *Single wire system.*—No. 5.—Cable 7 feet from compass, below deck, with a current of 30 ampères flowing; no deflection. No. 6. —Cable 7 feet from compass, above deck, with a current of 80 ampères flowing; half a degree deflection. No. 7.—Cable 5 feet from compass, below deck, with a current of 60 ampères flowing; slight deflection. No. 8.—Cable 2 feet from compass, above deck, 60 ampères flowing; 7 degrees deflection. The above tests were tried both with the cables fore and aft and athwart ships, and the effect upon the compass was practically the same in all cases. He then tried another experiment to ascertain the effect of the dynamo upon the compass, and placed a dynamo 8 feet from it. In the first experiment the dynamo was placed below the compass, and in the second experiment 8 feet below and 8 feet on one side, the dynamo being shielded by the deck above, with the result that there was no deflection on the compass. Of course different classes of dynamos would have different effects upon the compass, because in good machines there was very little stray magnetic field, but in inferior machines there was sometimes a very considerable stray magnetic field which would have a greater effect upon the compass. These experiments appeared to him to point out very conclusively that whether a ship was wired on the double wire system or not, for safety's sake all wiring near the compass should be on the double wire system, otherwise there was always a liability to error. Mr. Thomson in his remarks expressed a decided preference for the double wire system, whereas Mr. Holmes was equally strong in his preference for the single wire system. In addition to Mr. Thomson's objection to the single wire system on account of the deflection on the compass, he objected to the system on account of the joints being made to the hull of the ship; and although it might be the

practice of second-rate firms to make these connections to a deck bolt or some nut secured against a beam, yet good firms would not make their connections with the hull in this way; the practice being, as Mr. Holmes explained, to tap the hull and secure the wire by a brass screw and washer. This system of making connections was certainly to be preferred to the former; at the same time it was an objectionable system in his opinion, because ships were always liable to a certain amount of sweating, with the result that damp would accumulate round the joints, setting up an electrolytic action and causing a gradual eating away of the copper wire, the brass bolt, and the hull itself. To show what he meant he had made a connection to a piece of iron representing the hull in the way proposed by Mr. Holmes as being satisfactory. It had been moistened with water occasionally, and a current of 5 ampères passed through the connection fairly constantly for the last five weeks. For his part he considered such a contact not to be depended upon, as the result showed. [The metal exhibited.] A friend of his informed him some time since that in one ship that he had been connected with the electrolytic action set up between a joint and the hull had been so great that the hull of the ship was almost eaten through, and he was not at all surprised at this result, seeing that many connections were necessarily made in damp places; and although those in favour of the single wire system might argue that this action did not take place except in special positions, yet it was an action which they had to guard against. In the double wire system no contact was made with the hull, the electric light circuit being entirely distinct. All joints were thoroughly soldered and insulated in such a manner that damp could not get to them, the result being that it was very seldom, in a good installation, that leakage occurred; and as 99 per cent. of fires on board ship were caused either by excessive leakage, which gradually broke down the insulation and caused a short circuit, or by the contact of the single wire with the hull, it would be apparent that in a well planned installation on the double wire system a fire was almost an impossibility. On the other hand, with the single wire system, however well done it might be, there was always a possibility of the single wire being severed and contact made with the hull, and in the event of the fusible cut-out not fusing a fire was pretty well certain to occur. The Admiralty, who had probably as much experience of electric lighting on board ship as anyone, were now using the double wire system, he believed exclusively. Their cables were very thickly insulated with bitumen and braid and lead covered outside, the wires being secured by clips to the under side of the decks or bulkheads according to the position

they were run in. The single wire system undoubtedly had the merit of being much cheaper to install than the double wire system, and if carried out by experienced men had answered well; at the same time he failed to see where it offered any advantage over the double wire system, and most certainly there were very many important advantages possessed by the double wire system which did not apply to the single wire system.

Mr. Gray had brought before their notice the system known as Andrews's concentric wire system, the internal core being of copper and the return wire being of stranded iron wire, the iron wire making contact with the hull of the ship wherever it might touch. This was practically a single wire system, but the single wire was protected, being armoured by the iron wire outside. Certainly Mr. Andrews had shown considerable ingenuity in the method of making the joint and the general system, and although, provided the joints were well made, he should feel inclined to favour this system in preference to the ordinary single wire system, yet he still thought that the double wire system was preferable, and he did not think that in point of first cost that there was much, if anything, in favour of Mr. Andrews's concentric system.

Mr. Eugene Brown stated that the comparative efficiencies shown between the high tension alternating and low tension continuous current systems were based upon extreme cases. This he admitted, and the example was only given to show that, in particular cases where it was desired to distribute the current over a large area, the enormous advantage there was in using the alternating current system on full load, besides, as he pointed out, on light load with the low tension system it would be practically impossible to regulate the E.M.F. for the far distant lamps. In compact areas, such as the area lighted by the St. James and Pall Mall Electric Light Co., there was no doubt that the continuous current system was the proper one to use; on the other hand, assuming the central station to be placed at Deptford and the current having to be conveyed to London and then distributed over a large portion of the city, the alternating system had the advantage. The actual example from which his calculations were made arose from an enquiry his firm had recently received for lighting six large buildings abroad, the furthest one being 1,200 yards from the dynamo, and he prepared a calculation somewhat similar showing how impossible it would be to get anything like self-regulation over the system unless high tension alternating currents were used.

Mr. Walliker had given an illustration of the enormous deflection upon the compass, viz., 19 degrees, where a single wire ran 4 feet from

the compass, and this was quite sufficient illustration to point out the desirability of having ships wired upon a system where such errors could not arise. He thought shipbuilders would agree with him that it was better to avoid a cause of error than provide a remedy. He was extremely glad that Lloyd's Register had taken this subject in hand, and he hoped that they would as thoroughly thrash out electric lighting as they had shipbuilding and engineering. He was sure that the result of such an action on their part would eventually considerably improve the quality of the work done on board ship, in the same way that the rigid inspection of the Phœnix Fire Office improved the quality of work done in land installations, and he thought that Lloyd's would do well either to encourage their surveyors to obtain a thoroughly practical knowledge of the subject of electric lighting, or else employ at each large port a qualified electrical engineer to superintend the erection of all installations on board ship. He was sure the result would be that electric lighting would ultimately become universal, instead of hearing of failures due to bad workmanship as they did at the present time.

Mr. Sandison asked him for any particulars respecting the construction of the wrought iron steam pipes used by the St. James and Pall Mall Electric Light Company. He had communicated with the engineer, and received the following telegram:—"9 inch wrought iron, 150 lbs. pressure, running flanges butt jointed with copper rings for economy, but principally for reliability." His own experience exactly coincided with the reasons why the engineer to the St. James and Pall Mall Electric Light Company had used wrought iron pipes, and certainly on the score of economy and reliability he had a decided preference for wrought iron. As a matter of fact, wrought iron pipes were now coming very largely into use for all places where high pressure steam was being used, that is, for working pressures of from 80 to 150 lbs. per square inch. He had not seen Mr. Ferranti's arrangement of grouped copper pipes, and could not see that such an arrangement would be of any advantage, unless each pipe was fitted with its own stop valve, so that in the event of one pipe bursting that particular pipe could be shut off. There is no doubt that a number of small pipes would probably be safer than one large pipe; at the same time, experience had shown that large copper pipes, when properly made, were reliable. No doubt, however, Mr. Ferranti had good reasons for using the grouped copper pipes, which, however, had not been explained to him.

Mr. Newitt, he was very glad to hear, expressed himself very strongly in favour of the double wire system, and he was pleased to note that his

remarks were based on actual results, which were in all cases far more reliable than mere opinion, and would therefore be of very considerable value. He fully agreed with Mr. Newitt that the extra cost of the double wire system over the single wire system, on board a ship fitted with, say, 200 lights, would not exceed about £60, and when taking into account the many advantages possessed by the former system, he felt sure that shipowners would be disposed to pay this small extra price if only they clearly understood the great advantages the system possessed. Of course the cost of laying two wires would slightly exceed the cost of laying the single wire, but this would be to a great extent compensated for by the additional cost of drilling and tapping the holes in the hull of the ship for the return wires. Mr. Newitt's figures giving the deflection on the compass with single wires placed in various positions were extremely interesting, and are of great value on account of their reliability, and he thought that any practical shipowner would at once realise how extremely risky and unreliable a system of electric lighting must be in which there was a possibility of such an error in the compass occurring, and he quite agreed with Mr. Newitt when he stated that when these facts became known to shipowners single wiring would never be admitted again at sea, especially when it could be avoided, in ordinary sized ships, at an extra cost of about £60. He had had considerable experience in the construction of multipolar dynamos, and distinctly preferred the multipolar type of machine for large outputs, that is, in machines whose output exceeded 400 to 500 lights, and it was his practice to make four-pole machines with a capacity of 100 lights, *i.e.*, 6,500 watts, because in the Tyne type of dynamo, as made by his firm, the use of four poles allowed a special construction of armature, which was capable of being more readily repaired than any other type in the market, this being a matter of considerable importance in dynamos used at sea, where an accidental short circuiting of an armature coil would, in the case of most machines, entirely stop the lighting, whereas in the type of machine made by his firm such an accident occurring to the armature could be repaired by an ordinary fitter in a very short time. Further, by using an armature of large diameter more perfect ventilation was secured, and the machine consequently ran much cooler than a two-pole machine with a small armature. In practice it was also found difficult to wind the large conductors required for the heavy current of large dynamos, and it became necessary to laminate these wires to prevent excessive heating. By increasing the number of poles the section of wire on the armature was reduced in accordance with the number of poles, and therefore a much

smaller conductor could be used, which can be more easily wound, and is not subject to heating from eddy currents. He did not find in practice that the four-pole type of machine, as made by his firm, was at all an expensive one to build, and was most certainly much less complicated than many two-pole dynamos in the market. For instance, the Tyne four-pole dynamo can be taken entirely to pieces by removing the top half of the magnet frame, which was done by taking out eight bolts, and also taking off the bearing caps, the bearings being adjustable; the armature could then be lifted from its place, or examined in its bearings. With the two-pole type of machine, whether of the drum or cylinder type, it became necessary to take down the end bearing, and drag the armature through the field magnets before it could be lifted, which was, in his opinion, a most objectionable plan, as the insulation on the armature would very likely be considerably damaged. He did not think that Mr. Parsons's dynamo could be fairly compared with the ordinary commercial machine, on account of its excessive speed. Of course when the dynamos are run at, say, 10,000 revolutions per minute, it is only necessary to have a very few turns of conductor on the armature, which would be of large section, and of a very low resistance, consequently the loss of E.M.F., due to the resistance of the armature is extremely small, in fact almost negligible, therefore the dynamo only need be shunt wound; but in an ordinary dynamo for, say, 200 lights, which it was his practice to run at a speed of from 200 to 250 revolutions per minute when coupled direct to an engine, the armature resistance must necessarily be somewhat high, therefore the drop of E.M.F. between open circuit and full load would be somewhat considerable, and it therefore became necessary to keep the E.M.F. constant by compound winding the machine. Any attempt to use a shunt wound machine under these circumstances would involve considerable adjustment in the strength of the field magnets, by means of resistance coils, to keep the E.M.F. at the terminals of the machine constant, and therefore he did not think that shunt wound machines were suitable for running incandescent lamps direct. Mr. Newitt and Mr. Morrison had stated that a current density of 1,000 ampères per square inch section of copper was too high for large conductors. This he thoroughly agreed with, and if they would read his remarks on this subject they would find that he gave this density for cables carrying from 100 to 200 lamps only. As far as heating was concerned, he did not think that this density would be obj io le for cables even up to 500 ampères; but the great point to be co lered in determining the current density in a cable was the drop of po

the lamps, and it often became desirable to work at a very much lower density, in order to prevent a great variation in the lamps at the ends of the mains. The most satisfactory current density therefore varied in almost every case, but in ordinary installations in a mill, factory, private house, or public building, where the cables were not of large size, he thought that a current density of 1,000 ampères per square inch was a very satisfactory rule to work by, and if this density was not exceeded there would be no trouble from heating or any other cause. He regretted that he had not called attention to the accumulators which have been recently introduced by Messrs. Crompton & Howell, and Messrs. Drake & Gorham. The Crompton-Howell cells had, he believed, been used with great success by Messrs. Crompton at the Knightsbridge and other central stations, these cells being capable of very rapid discharges, but, as far as he knew, this type of cell had not been used much by outside contractors. The cell which Messrs. Drake & Gorham had just introduced, and which was manufactured for them by Messrs. Johnson & Phillips, had only been in the market for a very short time, and he had not personally had any experience with them; but as they were designed for rapid discharges, he thought there would be a large field for them, because it was often desirable to discharge a set of accumulators at considerably over their normal capacity, which would very rapidly spoil the old type of cell, as made by the Electric Construction Corporation. He quite agreed with Mr. Newitt that the efficiency of high tension alternating currents, quoted at 92 per cent., was rather high, but this efficiency was only intended to apply to the system when working at full load; of course when working at light load there would be a considerable loss in the transformers themselves, as they are not nearly so efficient at light load as they are at full load. In addition to this the generating plant would also be less efficient, so that the average efficiency for the whole system would be reduced. The same, however, applied to the low tension system, because this system on light load would show a falling off in efficiency also. He was in no way a partisan of either system. In many places where the lights were spread over a large area it would be impossible to distribute economically on anything else but a high tension system, whereas in closely populated districts, where the houses were grouped together, and a large quantity of light was required within a limited area, there was no doubt that the low tension distribution scheme was by far the most economical.

Replying to Mr. Arnison, he would like to remark that, although he had a decided preference for the double wire system, yet accidents were

just as likely to occur in an installation on the double wire system where the workmanship and materials were bad. He was sorry that he had taken so long in replying, but he hoped that someone more qualified than himself would contribute a further paper which would be more scientific perhaps than his; at the same time he thought it best to commence the subject from the beginning in as practical a way as possible.

The PAST-PRESIDENT (Mr. W. T. Doxford) said it was generally expected that the individual who had the honour of presiding at the meeting should say something on the subject read and the discussion. He was in the unfortunate position of not having heard the paper read, and still more unfortunate in knowing nothing of the subject. He should like to express his regret—probably shared in by others present—that they had not had the pleasure of hearing Professor Garnett, who knew a great deal about the subject before them. It was expected that he would have been present. Mr. Mountain seemed to express a regret that there had not been more discussion on his paper; but he thought that was easily accounted for by the subject being comparatively new, and by the want of extended experience with electric lighting in ships, as Mr. Nichol had pointed out. He had very great pleasure in moving a most hearty vote of thanks to Mr. Mountain for this very important paper, which he trusted they would receive in the usual way.

The vote was accorded by acclamation.

THE UNSINKABILITY OF CARGO-CARRYING VESSELS.

[SECOND PAPER.]

By W. HÖK, M.I.N.A.

[Read before the Institution, in Sunderland, April 10th, 1891.]

In a previous paper by the writer it was shown that, given certain conditions, the number of bulkheads provided in ships classed in Lloyd's is insufficient to keep them afloat in case they sustain any considerable damage through collision or other causes. These conditions for unsinkability, for natural reasons chosen as moderate as possible, as well as the method of investigation, were also laid before the members for criticism, with the result that the latter was found sufficiently accurate for the purpose, and the former inclined, if anything, towards leniency.

In the discussion on that paper it was further pointed out that it would be impracticable, be ruinous to trade, and increase the difficulties of the shipowner, if bulkheads exceeding in number the present requirements by Lloyd's had to be fitted. However, during the course of this paper, the writer will endeavour to show that the reasoning that underlies these arguments is fallacious, and that the effect of proper and efficacious subdivision will be the very reverse to what is generally put forward, and that, therefore, this change from bad to good, if it be ever carried out, will, instead of ruin, lead to a general increase in the prosperity of the people.

It may also be useful before the commencement of the investigation proper to enquire into the real reason why ships are, by rule, fitted with bulkheads. It can only be either—

(1) To provide safety,
(2) To provide strength, or
(3) To partition cargo spaces.

It is not difficult to show that bulkheads are not fitted for the purpose of providing strength. If they were fitted with this object in

view, they would neither require to be water-tight nor provided with water-tight doors, and, what is more important, it would be iniquitous to omit them in sailing vessels.

Nor are they put there as simple partitions, as in such a case they would neither require to be water-tight nor of the stipulated thickness or strength.

Hence it follows that bulkheads are primarily fitted for the purpose of providing safety to property and lives at sea.

It has previously been shown by the writer, theoretically, and by ships foundering almost daily, with considerable loss of life, practically, that the subdivision of ships, such as it is, is insufficient, and, consequently, useless.

It would therefore seem a reasonable proposition to omit the bulkheads (except the peaks) altogether, as such a change would undoubtedly cheapen ships, and place a number of people connected with shipping in a better position.

But no one will admit that such a retrograde step is desirable, as it would place those for whose benefit ships should be subdivided in a worse position than they are at present.

Why should, then, cargo-carrying vessels be properly subdivided and made practically unsinkable?

In order to provide protection for those beings who earn their living on the seas and those immediately dependent on them.

This reason, in conjunction with the proved fact that the present subdivision is inadequate, appears to the writer to be of sufficient weight to warrant an exhaustive enquiry into the possibility of so subdividing ships as to make them unsinkable, the best mode of effecting this subdivision, and, if it is found possible to efficiently subdivide ships, what is the least number of bulkheads required in ships of different forms, sizes, and types.

The carrying out of this enquiry, the explanation of the method of investigation employed, explanation sufficiently lucid and complete to enable others to grasp the method and use it, as well as hinting at the probable consequences of, and the best means for effecting, in the face of opposition, this much needed change in the present mode of subdividing cargo-carrying vessels form the subject-matter of the present paper.

It will not be denied that it is possible to so subdivide ships as to make them unsinkable, so the writer will at once enquire into the best way of effecting subdivision.

MODES OF SUBDIVISION.

There are, then, three different ways, either by means of :—

(1) Transverse bulkheads,

(2) Transverse and a longitudinal centre bulkhead,

(3) Horizontal flats and water-tight trunks,

or a combination of these three different methods.

A complete review of the various advantages of the different modes of subdividing would make the paper of undesirable length. The writer will therefore state at the outset that he advocates the sole use of the transverse mode of subdivision, and will attempt, as briefly as possible, to give sufficient reasons for this partiality :—

(1) Horizontal flats will be rendered useless in most collisions on account of their extending to the side of the ship at all points of their length. Their use must therefore be condemned.

(2) A centre longitudinal bulkhead is objectionable, because it necessitates simultaneous and very close transverse subdivision in order to minimise the list the ship would take in case water was admitted. Even if that list could be reduced by some other means, the longitudinal bulkhead would require transverse bulkheads and intermediate webs as support in order to resist the water pressure that would be brought to bear on it in case of collision.

It has been suggested, in defence of the longitudinal bulkhead, that the list can be disposed of by admitting water into another compartment at opposite side and end, but the writer doubts very much the advisability of such a course, as it would clearly be a case of experimenting with untested bulkheads at sea ; and he even believes that the courage required for carrying out this risky experiment would be found wanting in the hour of need. So therefore, in most cases, the list would remain, with all the possibly fatal consequences of cargoes shifting, causing the ship gradually to turn over ; and for this reason, as well as for the reason that it is preferable to have twice as much alteration in trim to list and alteration of trim combined, the use of the centre longitudinal bulkhead in cargo steamers must be condemned.

Subdivision with transverse bulkheads offers, then, the following advantages :—

(1) Less hindrance to stowage.

(2) Strengthens the ship transversely.

(3) Causes no list when water is admitted.

(4) Can be made of sufficient strength, at less cost, than any other kind of subdivision.

(5) And is almost invulnerable in case of collision.

It is true that a ship may be struck on one of her bulkheads, but the chance of this happening is indeed very remote, as far as the writer can see, especially in large ships; and although the chance of the bulkheads being struck will always lower the value of transverse subdivision, based on the assumption that such fatal blows will never be dealt, yet the fewness, or perhaps the total absence, of such occurrences justifies the assumption on which this investigation is based, that the transverse bulkhead is practically invulnerable in case of collision.

STRENGTH AND WATER-TIGHTNESS OF BULKHEADS.

There is reason to believe that, with the exception of the peak bulkheads, no bulkheads are perfectly water-tight in most ships. This subject, how to ensure water-tightness, as well as sufficient strength of bulkheads, and the advisability of fitting what is termed water-tight doors should be enquired into: the writer regrets that on account of the length of the paper he is here unable to discuss these most important points.

THE CONDITIONS FOR UNSINKABILITY.

The writer will now revert to the conditions for unsinkability; and he proposes for cargo-carrying vessels with *one* of the principal compartments in free communication with the sea :—

(1) The draught forward must not exceed 96 per cent. of the moulded depth to the bulkhead-deck plus one-half of the sheer forward.

(2) The draught at the middle of the length must not exceed 98 per cent. of the moulded depth to the bulkhead-deck.

(3) The draught aft must not exceed 97 per cent. of the moulded depth to the bulkhead-deck plus one-half of the sheer aft,

for an admission of 40 per cent. of water in the cargo spaces and 70 per cent. in the engine and boiler room.

It will be seen that the maximum draughts forward and aft differ slightly from those used in the previous paper. However, they are practically identical; but it was found when the influence of sheer was investigated, that it was not only more correct but much simpler to formulate the conditions as shown above.

It will also be seen that the writer has trusted to the invulnerability of the bulkheads, and made the assumption that the effect of the damage through collision is the free admission of water into only *one* compartment.

It will be said with truth that this is insufficient for absolute safety.

But the question arises, should cargo-carrying vessels be made absolutely unsinkable? or should they be a compromise between perfectly subdivided passenger steamers and ordinary vessels which have not even a ghost of a chance in case of collision? And the writer is inclined to think that to make cargo-carrying vessels, owing to the peculiar nature of their requirements, a compromise, and to trust to the invulnerability of the bulkheads, at least until experience proves otherwise, is the right way of solving the problem in hand.

And it must be admitted even by the most fastidious, and it is moreover borne out by experience, that the subdivision that fulfils the conditions for unsinkability previously laid down, would undeniably reduce to a very great extent losses of life and property at sea, and would, therefore, be a great improvement on the present insufficient requirements of the register societies. It would, in addition, have the good effect of placing all cargo vessels on equal footing with regard to safety, which in itself would be an improvement on the existing state of things, as it can not be just that some vessels should be safer than other vessels, and yet derive therefrom no special advantage.

And then, with the frank admission that the subdivision the writer will presently propose, and which is based on the conditions for unsinkability previously laid down, must rather be considered as the minimum subdivision required, due to the leniency of these conditions, than providing absolute safety under any circumstances for vessels built for general trading purposes, the investigation proper will be entered upon.

EXTENT OF THE INVESTIGATION.

Types of vessels.—In order to make the investigation complete, and to show the amount of subdivision required, and also the difference in the requirements for ships of different types, the following standard types are selected:—

(1) One, two, and three-deck vessels without erections.

(2) Vessels with erections consisting of poop, bridge, and forecastle, the total covering ·5 of the length of the vessel.

(3) Vessels with erections consisting of raised quarter-deck connected with bridge, and forecastle, the total covering ·7 of the length of the vessel (raised quarter-deck assumed 4 feet in height).

(4) Vessels with erections consisting of poop connected with bridge, and forecastle, the total covering ·7 of the length of the vessel.
(5) Vessels with erections consisting of raised quarter-deck connected with bridge, and forecastle, the total covering ·9 of the length of the vessel.
(6) Vessels with erections consisting of poop connected with bridge, and forecastle, the total covering ·9 of the length of the vessel.
(7) Awning-deck vessels with the bulkheads carried to the main-deck as per Lloyd's rules.
(8) Awning-deck vessels with the bulkheads carried to the awning-deck.
(9) Spar-deck vessels.
(10) Sailing vessels.

Fineness and proportions.—All these different types, with the exception of the sailing vessel, have been tried for two different finenesses, ·70 and ·79 (block coefficient of displacement), two different proportions, 12 and 15 depths in length, and two different sheers, the normal sheer, as per the freeboard tables, and this sheer increased by 50 per cent.

On the other hand, the sailing vessel has only been tried for one fineness, ·70, but two proportions, 10 and 13 depths in length, and also two sheers, the normal, and this sheer increased 50 per cent.

Draughts of Vessels.—The draughts at which the vessels are tested are their maximum draughts under ordinary conditions, these being Lloyd's summer load draughts; and it will therefore be understood that the minimum subdivision required only applies to ships when loaded to Lloyd's summer freeboards.

Lengths of vessels.—The lengths over which the investigation ranges is 160 to 420 feet, with the exception of the spar-deck vessel, due to the incompleteness of the freeboard tables, the lower limit of length for which is, on this account, fixed to 240 feet.

With regard to these limits of length, it was not found necessary to prosecute the investigation for longer ships, as, practically speaking, in no case are more bulkheads required for vessels above this length than presently prescribed by Lloyd's.

There were two reasons for fixing the lower limit to 160 feet: one was again the impossibility of ascertaining the exact freeboard for some other of the types; the other, the improbability of solving, in a practical way, the problem of subdivision for some types of smaller vessels when loaded to their present allowance of freeboard.

ASSUMPTIONS WITH REGARD TO THE VESSELS.

Peak bulkheads and engine and boiler compartment.—To fix the minimum number of bulkheads required, it is necessary to assume the position of the peak bulkheads, and the length and position of the engine and boiler compartment.

The former are placed in the same position as in the previous paper (see that paper, and also Table XV., page 351); and the length of the latter is identical to what was previously considered a fair length for the average steamer, being :—

$$\text{For vessels under 330 feet, } \frac{L}{10} + 15 \text{ feet,}$$

$$\text{,, over 330 feet, } \frac{L}{10} + 25 \text{ feet,}$$

if L is the length of the vessel, but its centre is, in this investigation, placed at the middle of the length of the vessel.

Sheer.—The sheer forward is, as before, assumed to be $\frac{4}{3}$, and the sheer aft $\frac{2}{3}$ of the mean sheer, or the sheer aft is $\frac{1}{2}$ the sheer forward.

Trim.—The trim of the vessel at the time of the accident is assumed to be on level keel.

These are all the assumptions necessary for fixing the minimum number of bulkheads, and also, in a general way, their position; and as these assumptions were not found unreasonable in the previous paper, the writer does not fear that they will here invalidate his general conclusions.

RESULTS OF THE INVESTIGATION.

The results of the investigation are now found in Tables XIV., XV., XVI., and XVII., pages 349-354. The figures these tables contain were lifted direct from a great number of diagrams, one of which is Diagram VIII., Plate XLVII., inserted as a sample. These diagrams give, for lengths of vessels from 160 to 420 feet, the positions from the after perpendicular of the various bulkheads, whereas the tables only give these positions at intervals of 20 feet of length of vessel. In some respects it would have been an improvement to have had these diagrams published, as necessarily a great many points, obscured in a table, would be clearly discernible on a diagram, but it was found impossible to make sufficient distinction between the great number of curves drawn on each diagram when printed in one or two colours only, and they were, therefore, omitted. However, it is an easy matter to find from the tables what is required by means of interpolation.

SUBDIVISION OF VESSELS.

Table XIV., page 349 then shows the number of intermediate bulkheads required for different lengths of vessels of the various types considered.

There are eight columns giving the lengths of vessels, one for every combination possible between the two selected finenesses, proportions, and sheers; and two columns giving the number of intermediate bulkheads required. It will be understood in interpreting these tables that the number of bulkheads there given do not include the four fundamental bulkheads in steamers, *i.e.*, the fore and after-peaks, and the two bulkheads forming the boundaries of the engine and boiler compartment, and that, therefore, in order to obtain the full number, add four for steamers and two for sailing vessels to the number given in the tables.

The most important fact established by this table is this—that the minimum subdivision required in any steamer is one intermediate bulkhead forward and one aft. It also indicates, what will undoubtedly be as interesting, the maximum subdivision required in any vessel within the range examined, this being in small awning-deck steamers with their bulkheads carried to the main-deck, namely, three intermediate bulkheads aft, two forward, and two in the engine and boiler space.

If this table is further studied, it will be seen that—

(1) SPAR-DECK STEAMERS are the steamers that require the minimum subdivision just mentioned, namely, one bulkhead aft and one forward, no matter what size they may be.

The maximum number of intermediate bulkheads required by—

(2) ONE, TWO, OR THREE-DECK STEAMERS WITHOUT ERECTIONS, is, two aft and one forward, and one divisional in the engine and boiler space.

(3) STEAMERS WITH POOP, BRIDGE, AND FORECASTLE, is, two aft, two forward, and one in the engine and boiler space.

(4) STEAMERS WITH POOP CONNECTED WITH SHORT BRIDGE is, two aft, two forward, and two in the engine and boiler space.

(5) RAISED QUARTER-DECK STEAMERS WITH SHORT BRIDGE, is, one aft, two forward, and two in the engine and boiler space.

(6) STEAMERS WITH POOP CONNECTED WITH LONG BRIDGE, three aft, two forward, and two in the engine and boiler space.

(7) RAISED QUARTER-DECK STEAMERS WITH LONG BRIDGE, one aft, two forward, and two in the engine and boiler space.

(8) AWNING-DECK STEAMERS, three aft, two forward, and two in the engine and boiler space; and

(9) SAILING VESSELS, a total of three intermediate bulkheads.

It also shows that the minimum subdivision for every type is one bulkhead aft and one forward for steamers and two intermediate for sailing vessels.

It may perhaps be instructive to here introduce a few statistics in connection with this matter. Lloyd's Register for last year shows that only 6·5 per cent. of the total number of vessels on their books are provided with six or more bulkheads, or, if wood and sailing vessels are excluded, that only 12·5 per cent. of all iron and steel steamers are so provided. It does not, however, follow that all these vessels fulfil the conditions for unsinkability, as they were picked out irrespective of type, etc.: the figures merely indicate the maximum percentage of vessels in Lloyd's Register Book that may possibly be unsinkable.

Table XIV., page 349 shows further that by extending the aftermost engine and boiler room bulkhead, and those in the after-hold, to the poop deck in steamers with long poop, these steamers will not require more bulkheads than the raised quarter-deck steamers, or by increasing the height of the bulkheads, as much as two intermediate bulkheads aft may be done away with without endangering the ship's safety; by extending all the bulkheads in the awning-deck steamer to the awning-deck, only one bulkhead aft and one forward are required, thus here, by a simple extension, doing away, in the worst case, with as many as two bulkheads aft, one bulkhead forward, and two in the engine and boiler space, or as many as five bulkheads.

The writer must here repeat that the number of intermediate bulkheads given in the table is based on the supposition that the engine and boiler compartment is in the centre. It is, however, possible in some cases, when the length of the ship approaches the upper limits of length for a certain subdivision, to so place the engine and boiler compartment either by shifting it aft or forward, as the case may be, as to reduce the number of intermediate bulkheads by one, but no more; but it was found a hopeless task to frame any general rule for this alternative.

By glancing further at Table XIV., it is seen that, supposing all the bulkheads extended to the same deck, and if the number required aft and forward is unequal, the extra bulkhead is always required aft. This is due to the sheer being considerably less aft than forward in ordinary vessels; and this occurrence points, therefore, forcibly to the fact that the

now fashionable distribution of sheer in ships stands urgently in need of revision.

It will also be noticed, what will appear extraordinary to a great many, that the smaller the ship of a given type is, the more bulkheads she requires, or conversely, the bigger she is, the smaller is the number she requires. This is really contrary to all practice, and contrary to the rules of all classification societies, but is, nevertheless, correct; and the writer believes that he will have little difficulty in dispelling the old and erroneous notion that big ships require, relatively speaking, more minute subdivision than small ones. As, however, the proof needed for throwing over this erroneous notion involves a discussion of the formulæ proposed for this kind of work, it will be given in its completeness in an Appendix (see Appendix A); and the writer will therefore merely state his case here in a superficial way.

The reason, then, why large ships, say of equal fineness, sheer, and proportions, require a smaller number of bulkheads than small ones is due to the fact that the number of bulkheads required is entirely independent of absolute size, and depends solely on the draught in relation to depth.

Therefore any change that tends to decrease the draught in relation to depth will reduce the number of bulkheads required. The freeboards of vessels furnish such a change. It is a well-known fact, although a very strange one, that, as ships increase in size, the ratio of load draught to depth decreases; consequently it follows directly that with increase of size there is a corresponding reduction in the number of bulkheads required.

The engine and boiler space.—With regard to this space, it will be noticed that some ships require one divisional bulkhead in the engine and boiler space. The writer will pass over these ships, as it is possible, without great inconvenience, to so subdivide this space, and turn his attention at once to other ships for which one subdivision there is insufficient.

No one will deny that there are insurmountable obstacles in the way of having two subdivisions in the engine and boiler space in ordinary cargo-carrying vessels, and therefore the question of subdividing this space in some small steamers merits special attention.

The table shows that these steamers are small awning-deck steamers with bulkheads to the main-deck, and small steamers with erections covering ·9 and ·7 length of vessel respectively. The difficulty with the awning-deck steamer is easily overcome by carrying all her bulkheads to the upper-deck, when she would require no subdivision at all in the engine and boiler space.

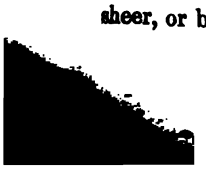
Small steamers with erections covering ·9 length may possibly do away with the second divisional bulkhead by carrying the engine and boiler room bulkheads up to the bridge-deck, so the difficulty arises in connection with the steamers having erections covering only ·7 length. If in these steamers the same means were resorted to as proposed in the previous type they would hardly be left with sufficient freeboard in front of bridge in case of damage to their engine and boiler compartment. So this point brings to light the fact that the difficulty of providing adequate subdivision in the engine and boiler space in some cargo-carrying vessels puts a limit to the draught to which ships should be loaded. This limit for draught at which one subdivision in the engine and boiler space ceases to be sufficient is at a draught equal to 92 per cent. of the depth; and as some smaller ships of a few types are allowed to load to a deeper draught, this fact merits consideration at the next revision of the freeboard tables.

Finally, Table XIV., page 349 shows indirectly the influence of fineness, proportions, and sheer on the number of the bulkheads. It will be noticed that, although that influence causes an alteration in the position rather than a decrease in the number of bulkheads, it is not impossible to so choose the dimensions and form of the ship as to reduce the number of bulkheads required by one and, in some instances, by two.

Table XV., page 351 gives the absolute positions, reckoned from the after perpendicular, of the bulkheads, and the maximum lengths of the engine and boiler compartment of a standard vessel of ·700 in fineness, 12 depths in length, and normal sheer, and of varying lengths from 160 to 420 feet. It will be understood that these distances are maximum distances for the bulkheads in the after-hold, and minimum distances for those in the fore-hold, and that therefore the after bulkheads can be shifted further aft, and the fore ones further forward, without any harm being done; but if this shifting of bulkheads is resorted to no hold must be made longer than shown by Table XV. for the bulkheads in their maximum and minimum positions respectively.

Table XVI., page 353, gives the distances in feet which the bulkheads must be shifted, either forward or aft, from the positions indicated in Table XV., and the amount by which the engine and boiler space can be lengthened or shortened, for vessels 15 depths in length.

Table XVII., page 354, gives in percentage of the length of the vessel how much the bulkheads must be shifted forward or aft, as the case may be, and how much the engine and boiler space can be lengthened or shortened by altering the fineness to ·79, by adding 50 per cent. more sheer, or by a combination of both.



In these Tables (XVI. and XVII.) the positive sign indicates that the hold bulkheads must be shifted forward, thus indicating improvement aft and change for the worse forward, and that the engine and boiler room can be lengthened, thus here indicating improvement too.

The negative sign, of course, indicates these conditions reversed.

It is therefore possible, by means of these Tables, to ascertain the exact positions of the bulkheads, and the exact length of the engine and boiler-room, so as to preserve the conditions for unsinkability, for any steam vessel between ·70 and ·79 in fineness, between 12 and 15 depths in length, and provided with a sheer between the normal and an increase of 50 per cent. How this interpolation is executed will be shown in Appendix B. Here will only be mentioned the most general effects of a change in the fineness, proportions, or sheer.

These Tables (XIV., XVI., and XVII.) then show that fulness of form is detrimental to unsinkability in the case of the end compartments, but advantageous in the case of the centre compartment.

That increase of length in relation to depth has the effect of slightly improving small ships and making big ships worse, but to a different degree in different types, dependent on draught, and the influence of sheer on draught. (This subject was discussed in the previous paper.)

That increase of sheer has a most beneficial effect on the end compartments, the degree, however, being dependent of the influence of sheer on the freeboard, being greatest in spar and awning-deck vessels and smallest in one, two, and three-decked vessels without erections, and a detrimental effect on the engine and boiler compartment, except for spar and awning-deck steamers where the effect is none.

This is, in brief, the complete investigation. But it is perhaps advisable to give a *résumé* of the principal alterations proposed, and generally enumerate the changes that would improve the safety of life and property at sea.

(1) Maximum freeboard, ·92 depth.

(2) More sheer, especially aft.

(3) Extending the bulkheads—

(a) In awning-deck vessels to the awning-deck.

(b) In steamers with poop connected with long bridge, aft, and engine and boiler room bulkheads, to the poop-deck.

(c) In steamers with poop connected with short bridge, aft, and aftermost engine and boiler room bulkhead, to the poop-deck.

(4) One subdivision in the engine and boiler room when required.
(5) One intermediate bulkhead aft and one forward for all lengths.
(6) Three intermediate bulkheads in small and two in large sailing vessels.
(7) Shifting the fore-peak bulkhead further aft in most types when the foremost cargo space is not required for cargo purposes.
(8) Testing the peak bulkheads to the upper-deck.

From what has been previously shown with regard to the requirements for unsinkability, it is impossible to deny that the alterations just proposed would, if not totally, yet to a very great extent, increase the safety at sea. It would, moreover, do so without hampering the shipowner or interfering with stowage.

Even fitting the number of bulkheads proposed in sailing vessels cannot materially interfere with the prosperity of the owners; and, whether it does or not, the fact remains that sailing vessels without bulkheads are a disgrace, especially as these totally unprotected vessels are permitted, and sometimes carry hundreds of lives from one part of the world to another; and the announcement made by the Inspector-General of Bureau Veritas, M. Piaud, in the discussion on the previous paper, that a special mark is in the future to be given to sailing vessels provided with bulkheads must therefore be hailed with the utmost satisfaction.

These less objectionable features being carried out, it only remains to consider if the further subdivision required in some cases, which subdivision, in fact, merely consists of an additional bulkhead aft or forward, or both at the most, in order to make ships practically unsinkable, would, indeed, damage the owners' interest to such an extent as to cause ruin if carried out.

This problem will be best solved by answering the following questions:—

(1) What advantage would be derived from the proposed change in the subdivision of ships?

If introduced:

(2) Who would suffer by this change?
(3) And who would benefit by it?

The first question has been answered over and over again during the course of the paper, namely, that proper subdivision will increase the safety of life and property at sea. Hence it follows directly that the vessels, cargoes, and freights can be insured at a much lower rate than at present.

Who would suffer by this change?

(1) *The underwriters and insurance companies*, on account of reduced business.

(2) *The shipbuilder*, on account of fewer losses, and, consequently, fewer ships to replace.

Who would then benefit by this change?

(1) *The shipowner*, by the reduction of the exorbitant rates of insurance now annually paid for ships and freights, which reduction should be greatly in excess of the interest on the amount involved in the extra cost of ship.

(2) *The merchant*, by reduction of the insurance on the cargo.

(3) *The people* in general, by the merchant being able to sell cheaper on account of reduction in the insurance.

And last, but not least,

(4) *The seafaring men*, and those immediately dependent on them.

Thus it is suggested that the two parties principally concerned, the sailor and the shipowner, would both benefit by the introduction of this proposed change, the sailors unconditionally, but the shipowner only on the condition that the insurance of ships and freights was reduced.

Under these circumstances the question arises, which would be the best way of effecting this much needed change?

Undoubtedly by inducing the underwriters and insurance companies to lower the rates of insurance for unsinkable ships. This is, indeed, the key to the whole question. If that was found impossible, an insurance company should be formed that insured unsinkable ships at greatly reduced rates.

Then the writer believes that the shipowner, seeing the advantages offered him, would reconsider his present notions with regard to the ruinous consequences of efficient subdivision, and thereby obviate the necessity for those laws that are now under consideration for the protection of human life at sea.

In conclusion, although this investigation extends over two papers of over average length, the subject of the unsinkability of ships is far from exhausted.

It is plain that here is a rich and opportune field for investigation, as the subject is too important to be any longer treated with indifference.

It is to be hoped that other investigators will come forward and contribute to its completion.

And it is also to be hoped that, through the combined efforts of many workers, sufficient attention will be drawn to the subject, that something of a practical nature, which would benefit the seafaring community, will be the ultimate result.

		ess, '70. tions, 15. normal.	Fineness, '79. Proportions, 15. Sheer, normal.	Fineness, '70. Proportions, 15. Sheer, 50 °/₀	Fineness, '79. Proportions, 15. Sheer, 50 °/₀.
1	Awning-deck.	r 330	under 330	...	...
		o 380	330 to 390	...	...
		o 430	390 to 440	under 400	under 410
		r 430	over 440	over 400	over 410
		r 285	under 265	under 285	under 265
		o 425	265 to 405	285 to 425	265 to 405
		r 425	over 405	over 425	over 405
2	Vessels lengt	r 295	under 295	...	...
		o 355	295 to 365	...	...
		o 410	365 to 420	under 380	under 390
		r 410	over 420	over 380	over 390
		r 260	under 240	under 260	under 240
		o 400	240 to 380	260 to 405	240 to 385
		r 400	over 380	over 405	over 385
3	Previous and b	r 355	under 365	...	...
		r 355	over 365	for all lengths.	
4	Vessels bridg ing 2	however, the foremost engine and boiler room quired in the latter space.			
5	Vessels len	r 300	under 300	...	...
		o 370	300 to 385	under 335	under 350
		r 370	over 385	over 335	over 350
		r 210	under 185	under 215	under 190
		o 330	185 to 310	215 to 340	190 to 320
		r 330	over 310	over 340	over 320
6	Previous engine	r 300	under 300	...	...
		r 300	over 300	all lengths.	all lengths.
		(5).			
7	Vessels bridg coveri	ine and boiler room bulkhead to the poop-deck.			
8	Vessels erecti	...	...	...	...
		r 295	under 305	under 260	under 270
		r 295	over 305	over 260	over 270
		r 270	under 250	under 290	under 270
		r 270	over 250	over 290	over 270
9	One, two,	ngths.	all lengths.	all lengths.	all lengths.
		r 210	under 185	under 235	under 205
		r 210	over 185	over 235	over 205
10					
11	Awning-d				

Proportions, 13. r, 50 °/₀
ler

TABLE XVI.

Showing the amount in Feet by which the Distances and Maximum Lengths in Table XV. are to be Corrected, so as to give the True Positions of the Bulkheads, and the Length of the Engine and Boiler Space, in Steamers 15 Depths and Sailing Vessels 13 Depths in Length.

Type of Vessel.	Position of Bulkhead.	Length of Vessel.					
		200	240	280	320	360	400
One, two, and three-deck vessels, without erections.	1st aft ...	+ 2	+ 2	+ 3	+ 3	+ 2	+ 1
	E. and B. room	0	0	− 1	− 2	− 3	− 4
	1st forward ...	− 3	− 3	− 3	− 3	− 4	− 4
Vessels with poop, bridge, and forecastle, the erections covering ·5 length.	1st aft ...	+ 1	0	− 1	− 2	− 3	− 4
	2nd aft ...	+ 5	+ 3	+ 1	...	...	...
	E. and B. room	0	− 1	− 2	− 4	− 6	− 8
	1st forward ...	− 3	− 3	− 3	− 2	− 1	0
Vessels with long poop, the erections covering ·7 length.	1st aft ...	+ 2	0	− 2	− 4	− 6	− 8
	2nd aft ...	+ 3	+ 1	− 3	−12	...	...
	E. and B. room	− 2	− 4	− 7	−10	−14	−20
	2nd forward ...	− 9	− 6	− 3	...	...	...
	1st forward ...	− 3	− 2	0	+ 2	+ 4	+ 7
Raised quarter-deck, erections ·7 length.	1st aft ...	+11	+ 9	+ 7	+ 4	+ 1	− 2
Vessels with long poop, the erections covering ·9 length.	1st aft ...	+ 1	0	− 2	− 5	− 8	−12
	2nd aft ...	+ 4	+ 3	− 1	−13	−27	...
	3rd aft ...	+ 6	+ 5	− 2	...	...	...
	E. and B. room	0	− 3	− 7	−11	−16	−22
	2nd forward ...	− 9	− 9	− 6	+ 4	...	...
	1st forward ...	− 3	− 2	0	+ 2	+ 4	+ 7
Raised quarter-deck, erections ·9 length.	1st aft ...	+10	+ 8	+ 6	+ 3	0	− 4
Awning-deck vessels with bulkheads to the main-deck.	1st aft ...	+ 2	+ 1	− 2	− 5	− 8	−12
	2nd aft ...	+ 4	+ 3	0	−11	−24	−39
	3rd aft ...	+ 7	+ 6	− 2	...	...	...
	E. and B. room	0	− 2	− 4	− 8	−15	−26
	2nd forward ...	−13	0	+ 4	+ 9	...	...
	1st forward ...	− 5	− 3	0	+ 3	+ 6	+10
Awning-deck vessels with bulkheads to the awning-deck.	1st aft ...	...	+21	+15	+ 9	+ 4	− 1
	E. and B. room	...	+16	+11	+ 6	+ 2	− 2
	1st forward ...	...	...	...	...	...	...
Spar-deck vessels.	1st aft ...	...	...	...	+13	+10	+ 4
	E. and B. room	...	...	...	+12	+ 6	0
	1st forward ...	...	...	...	−19	−14	− 8
Sailing vessels.	Aft	+ 2	+ 3	+ 3	+ 3	...	...
	Centre ...	+ 1	0	− 2	− 5	...	...
	Forward ...	− 4	− 4	− 5	− 6	...	...

TABLE XVII.

Showing the amount in Percentage of Length of Vessel by which the Distances in Table XV. are to be Corrected, so as to give the True Positions of the Bulkheads, and the Length of the Engine and Boiler Space, in Vessels of ·79 fineness, or 50 per cent. increase of Sheer, or Both.

NOTE.—Vessels of 15 Depths in Length are first to be Corrected by Table XVI.

Position of Bulkhead.	Fineness, Proportions, Sheer.	Awning-deck, Bulkheads to Main-Deck.	Long Poop, Erections ·9 Length.	Long Poop, Erections ·7 Length.	Erections ·5 Length.	Without Erections.	Raised Quarter-deck, Erections ·9 Length.	Raised Quarter-deck, Erections ·7 Length.	Spar-deck.	Sailing Vessel.
1st aft.	·79; 12; normal	− 1·0	− 1·0	− 1·0	− 1·5	− 1·5	− 1·5	− 1·5	− 1·5	...
	·70; 12; 50 %	+ 1·5	+ 1·0	+ 1·0	+ 1·0	+ ·5	+ 1·0	+ 1·0	+ 1·5	0
	·79; 12; 50 %	0	− ·5	− ·5	− 1·0	− 1·5	− ·5	− ·5	0	...
	·79; 15; normal	− 1·0	− 1·0	− 1·0	− 1·0	− 1·5	− 1·5	− 2·0	− 1·5	...
	·70; 15; 50 %	+ 2·0	+ 1·5	+ 1·0	+ ·5	0	+ 1·5	+ 1·0	+ 2·5	0
	·79; 15; 50 %	+ 1·0	+ ·5	0	− ·5	− 1·5	0	− 1·0	+ 1·0	...
2nd aft.	·79; 12; normal	− 1·0	− 1·0	− 1·0	− 1·0	...	...	...	...	...
	·70; 12; 50 %	+ 4·0	+ 3·5	+ 2·5	+ 2·0	...	...	...	...	...
	·79; 12; 50 %	+ 3·0	+ 2·5	+ 1·5	+ 1·0	...	...	...	...	...
	·79; 15; normal	− 1·0	− 1·0	− 1·0	− 1·0	...	...	...	...	...
	·70; 15; 50 %	+ 5·0	+ 4·5	+ 3·5	+ 3·0	...	...	...	...	...
	·79; 15; 50 %	+ 4·0	+ 3·5	+ 2·5	+ 2·0	...	...	...	...	...
3rd aft.	·79; 12; normal	0	0	...	...	...	...	...	...	...
	·70; 12; 50 %	+ 6·5	+ 6·5	...	...	...	...	...	...	...
	·79; 12; 50 %	+ 6·5	+ 6·5	...	...	...	...	...	...	...
	·79; 15; normal	0	0	...	...	...	...	...	...	...
	·70; 15; 50 %	+ 9·0	...	...	...	...	...	...	...	...
	·79; 15; 50 %	+ 9·0	...	...	...	...	...	...	...	...
Engine and Boiler Compartment.	·79; 12; normal	+ 1·5	+ 1·5	+ 1·5	+ 2·0	+ 2·5	...	...	+ 2·0	...
	·70; 12; 50 %	0	− 1·0	− 1·0	− 1·5	− 2·5	...	...	0	− 3·0
	·79; 12; 50 %	+ 1·5	+ 1·0	+ 1·0	+ 1·0	+ ·5	...	...	+ 2·0	...
	·79; 15; normal	+ 1·5	+ 1·5	+ 1·5	+ 2·0	+ 2·5	...	...	+ 2·0	...
	·70; 15; 50 %	0	− 1·0	− 1·0	− 2·0	− 2·5	...	...	0	− 4·0
	·79; 15; 50 %	+ 1·5	+ 1·0	+ 1·0	+ ·5	+ ·5	...	...	+ 2·0	...
2nd forward.	·79; 12; normal	+ 1·0	+ 1·0	+ 1·0	...	...	...	...	...	...
	·70; 12; 50 %	− 8·5	− 8·5	− 8·5	...	...	...	...	...	...
	·79; 12; 50 %	− 7·5	− 7·5	− 7·5	...	...	...	...	...	...
	·79; 15; normal	+ 1·0	+ 1·0	+ 1·0	...	...	...	...	...	...
	·70; 15; 50 %	−13·0	...	...	...	...	...	...	...	...
	·79; 15; 50 %	−12·0	...	...	...	...	...	...	...	...
1st forward.	·79; 12; normal	+ 1·5	+ 1·5	+ 1·5	+ 1·5	+ 1·5	...	...	+ 2·0	...
	·70; 12; 50 %	− 3·0	− 2·5	− 2·5	− 2·0	− 1·5	...	...	− 3·5	− 1·5
	·79; 12; 50 %	− 1·5	− 1·0	− 1·0	− ·5	0	...	...	− 1·5	...
	·79; 15; normal	+ 2·0	+ 1·5	+ 1·5	+ 1·5	+ 1·0	...	...	+ 2·0	...
	·70; 15; 50 %	− 4·0	− 3·5	− 3·0	− 2·5	− 2·0	...	...	...	− 2·0
	·79; 15; 50 %	− 2·0	− 2·0	− 1·5	− 1·0	− 1·0	...	...	...	...

APPENDIX A.

The formulæ proposed in the previous paper have been used in the present investigation in the following way:—

Denoting the moulded draught forward after the admission of water by D, the formula (I.) for the additional draught forward

$$= \frac{\sigma \times d}{an - 12\gamma_1^2}\left[a + 12\gamma(1-\epsilon)\right]$$

was written:—

$$D = d + \frac{\sigma \times d}{an - 12\gamma_1^2}\left[a + 12\gamma(1-\epsilon)\right], \text{or}$$

$$\frac{D}{d} = 1 + \frac{\sigma\left[a + 12\gamma(1-\epsilon)\right]}{an - 12\gamma_1^2}$$

$$= 1 + \frac{\sigma\left[a + 12\gamma(1-\epsilon)\right]}{\frac{1}{\delta} \times a \times \frac{A}{a} - (a + 12\gamma_1^2)} \quad \ldots \quad \text{(V.)}$$

This formula is now an expression for the draught forward after the admission of water divided by the mean draught before admission; it is therefore a ratio, and as such independent of absolute dimensions.

For similar forms of vessels, loaded to equal draught ratios, a and ϵ are constants, σ, γ, γ_1, and $\frac{A}{a}$ vary with the relative lengths and positions of the compartments, and δ is the percentage of water admitted. And in the case of similarity of subdivision, added to similarity of form, all these ratios are constants, from which follows that, in the case of perfect similarity, the expression (V.) is a constant too. And it will be thus seen that the draught forward or aft, after admission, depends on no other absolute dimension than the original load draught, being independent of length and breadth.

Turning now to Diagrams I. and II., Plates XL. and XLI., which diagrams are constructed by means of the previous formula (V.), and Diagram III., Plate XLII., constructed by means of formula (IV.) in the previous paper, it will be immediately noticed that it is highly advantageous, if fewness of bulkheads is aimed at, to provide as great a value of $\frac{D}{d}$ as possible. This can only be effected in two ways, either by increasing the maximum draught (D), by increasing depth and sheer, or by decreasing the mean draught (d). The number of bulkheads for similar forms of ships, and for the same percentage of water admitted, being solely dependent on this value $\frac{D}{d}$, it is easy to understand the

superiority of high freeboard vessels, or of spar-deck vessels over one, two, and three-deck vessels without erections, these latter vessels over those with erections, and so on.

THE USES OF DIAGRAMS I., II., AND III., PLATES XL., XLI., AND XLII.

The uses of Diagrams I., II., and III. are best understood by a few examples.

Example I.—Assume that it was decided to fix the number and positions of the bulkheads of the following vessel :—

Length, 300 feet.
Breadth, 40 „
Draught, 20 „
Fineness, ·700.
Ignore length and breadth.

Judge by the depth and the amount of sheer what is the greatest draught that the vessel could safely be immersed to in the case of *one* compartment being in communication with the sea, say 23 feet forward and 22 feet aft.

Find now the ratios of the draughts fore and aft after admission to the draught before admission, these being—forward, 1·150, and aft, 1·100. Fix the positions of the peak bulkheads, say forward at ·925 and aft at ·050 length of vessel.

Run along the draught ratio line forward (Diagram I.) until it intersects the curve marked ·925, and read off the corresponding abscissa. Its value is ·805, and indicates the position of the first bulkhead forward.

Run again along the draught line, and where it cuts the curve marked ·805 is the position of the second bulkhead, being at ·686 of the length of vessel. Continuing to run along the same line, it is seen that no more bulkhead is required forward.

If the same performance is repeated for the after-body, but on the draught line marked 1·100, and with the peak bulkhead as fixed above, the positions of the bulkheads aft are found to be at ·154, ·234, ·317, and ·422 length of vessel.

The engine and boiler compartment being fixed, say 45 feet, it remains to ascertain if this compartment requires to be subdivided, which is easily done by Diagram III. when the draught ratio is fixed.

Example II.—In case the bulkheads of a vessel are already fixed, it may be desirable to know whether the vessel is practically unsinkable or not. Find the distances of the bulkheads from the aft perpendicular, and divide by the length of the vessel. Assume, then, that the forward

bulkheads are placed at ·58, ·72, and ·95 length. Say that the load draught is 20 feet, and the maximum draught forward, after admission, is 26 feet. The draught ratio being now 1·300, find the intersection between abscissæ, ·58, ·72, and ·95, and the draught ratio line, 1·300.

It is then seen that the main-hold is short enough, as it could be extended to ·822 length without violating the conditions for unsinkability, but that the fore-hold is too long. This matter can easily be put right, as shown by the diagram, either by shifting the fore-peak bulkhead aft to ·93 length, or the intermediate bulkhead forward to ·732 length.

Example III.—The question may be reversed. Given certain compartments, to what draught would the vessel sink if water was admitted?

Say that the bulkheads are placed at ·750 and ·925 length.

The intersection between the vertical line from ·750 length and the curve marked ·925 gives the draught ratio, being in this case 1·240. If, then, the draught before admission was 25 feet, the draught forward after admission would be 31 feet.

Example IV.—Or, assuming the positions of the fore-peak and boiler room bulkheads fixed, to find the most advantageous position of the intermediate bulkhead, *i.e.*, the position where the draught ratios would be equal, and a minimum, in case either of the fore compartments was damaged.

Say that the fore-peak bulkhead is placed at ·930 length of vessel, and the boiler room bulkhead at ·580 length. Run up along the vertical line through ·580 length, and, simultaneously, run down along the curve marked ·930. It is then easily seen that the most advantageous position of the intermediate bulkhead is at ·770 length of vessel, and that the corresponding draught ratio for both compartments is 1·212.

Example V.—The previous examples suppose the trim of the vessel to be on even keel. But if the trim is either by the head or stern, the proper subdivision is found in the following way:—

Say that the vessel is 2 feet by the stern.

Mean draught, 20 feet.

Thus draught aft, 21 feet; and draught forward, 19 feet.

Settle on draught aft after admission, say 24 feet.

And „ forward „ „ 26 feet.

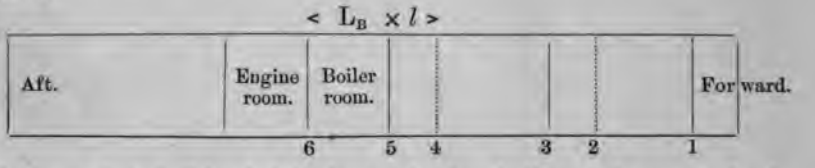
Showing an additional immersion of 3 feet aft and 7 feet forward.

Add these to the mean draught, and use as maximum draughts aft and forward, 23 and 27 feet respectively, for forming the draught ratio, instead of 24 and 26 feet; and the ensuing result will be the subdivision required for the vessel being 2 feet by the stern.

Diagram II. (similar to I.) is constructed for vessels with a block coefficient of displacement of ·790; and used in conjunction with Diagram I., it is easy to find the subdivision required for any intermediate fineness by interpolation.

It will be understood that these Diagrams (I., II., and III.) are also capable of solving with sufficient precision the interesting problem—what subdivision is required, if two or more adjoining compartments are supposed to be simultaneously bilged?

Assume the fore-peak 1, and boiler room bulkheads 5 and 6, to be fixed.



Suppose that bulkhead 2 is damaged, then bulkhead 3 can be fixed directly by the aid of Diagram I. Then assume bulkhead 5 damaged and fix bulkhead 4. This can only be done in an approximate way by means of the diagrams, as the boiler room admits 70 per cent., and the compartment 4-5, 40 per cent. of water. Call the length of the boiler room L_B and the hold 4-5, l. Find from Diagram I. the maximum length of a compartment at the approximate position of 4-6, for an admission of 40 per cent. of water $= L_{max.}$; and the compartment 4-5 may be approximately taken as $l = L_{max.} - \frac{7}{4}L_B$; or if Diagram III. is used $l = \frac{7}{4}(L'_{max.} - L_B)$. When, now, bulkhead 4 is fixed, bulkhead 2 can be directly found from Diagram I., assuming bulkhead 3 to be damaged. The bulkheads of the after-body are, of course, fixed by a similar procedure.

Diagrams IV., V., VI., and VII., Plates XLIII., XLIV., XLV., and XLVI., are directly obtained from Diagrams I. and II. They show at a glance the positions and minimum number of bulkheads required for two different positions of peak bulkheads (5·5 and 8·0 per cent. from the ends) for any given draught ratio.

It is by this means possible to appreciate the effect of lengthening or shortening the peaks, and also to find the positions, of the intermediate bulkheads for any ordinary length of the peaks by means of simple interpolation.

These diagrams show in an unmistakable manner the effect of increasing the draught ratio, or the influence of freeboard and draught, on the number and positions of the bulkheads. For the vessel with a fineness of ·700, if the draught ratio is, roughly speaking, over 1·200, only

one intermediate bulkhead is required at each end; between 1·130 and 1·200, two at each end; between 1·100 and 1·130, three at each end; and, if it is as low as 1·050, six at each end for the fine, and seven for the full ship.

Diagram VIII., Plate XLVII., represents part of one of the final diagrams from which the figures in Tables XIV. to XVII., pages 349-354, are lifted. These final diagrams are obtained by combining Diagrams III., IV., V., VI., and VII., Plates XLII., XLIII., XLIV., XLV., and XLVI., with the load draught ratios (obtainable by dividing the draughts, forward, middle, and aft, that fulfil the conditions for unsinkability, with Lloyd's summer load draught) that appertain to the various lengths of vessels of each type, fineness, etc.

The positions of the bulkheads for each type being found, they were laid down as shown on Diagram VIII, Plate XLVII.

APPENDIX B.

The use of Tables XV., XVI., and XVII., pages 351-354, is best understood by an example. Required to know the position of the forward bulkhead in a steamer with poop, bridge, and forecastle, 350 feet long, ·745 in fineness, 13·5 depths in length, and a mean sheer exceeding Lloyd's by 25 per cent.

Find from Table XV. the position of the bulkhead for a ship ·700 in fineness, 12 depths in length, and normal sheer; from Table XVI. its position for a ship 15 depths in length; and from Table XVII. the positions for the remaining standard forms by correcting for sheer and fineness.

Combine the results in the way shown in the annexed table (Table XVIII.), and the required position is found.

TABLE XVIII.

From Tables.	Positions of Bulkheads.	Corrected for Fineness.	Positions of Bulkheads.	Corrected for Fineness and Sheer.	Positions of Bulkheads.	Corrected for Fineness, Sheer, and Proportions.	Final Position of Bulkhead.
·70; 12; normal	253·5	·745; 12; normal	256·1				
·79; 12; normal	258·7			·745; 12; 25 %	252·6		
·70; 12; 50 %	246·5	·745; 12; 50 %	249·1				
·79; 12; 50 %	251·8					·745; 13·5; 25%	251·6
·70; 15; normal	252·3	·745; 15; normal	254·9				
·79; 15; normal	257·5			·745; 15; 25 %	250·6		
·70; 15; 50 %	243·6	·745; 15; 50 %	246·2				
·79; 15; 50 %	248·8						

DISCUSSION.

The PAST-PRESIDENT observed that those of them who had had the pleasure of hearing the two papers read by Mr. Hök on the subject of bulkheads, and the discussions that had taken place at Hartlepool and Newcastle, might be astonished to see how much could be said on what, at first sight, might seem a very simple subject. He thought they would all agree that Mr. Hök had devoted a large amount of time, patience, and ability to the preparation of these papers. The discussion would be continued on Saturday, 25th April, at Hartlepool; but meanwhile there might be someone prepared to go on with it. He thought probably there was nothing the writer of a paper liked better than to have some adverse criticism to give him an opportunity later on of putting the speakers right if he could.

Mr. H. MACOLL was afraid that the paper before them was rather too elaborate and extensive in its scope to admit of impromptu criticism. The subject was one that required a good deal of consideration and study. However, in obedience to the call of the Past-President, he would endeavour to make a very few remarks; and, generally, he was prepared to go a good way with Mr. Hök in the conclusions arrived at. Although there was a shade too much of what might be called the moral philosophy element in the paper for him to accept *in toto*, he thought that element might very suitably be relegated to a very minor position and only touched in an incidental manner. On page 336 it was said in the paper "It will not be denied that it is possible to so subdivide ships as to make them unsinkable." Now, to start with, he (Mr. Macoll) was not prepared to admit that. In the paper the matter was considered pretty much from what might be termed the collision *versus* bulkhead point of view. It must be evident from a very cursory examination that the great bulk of the loss of ships and lives does not arise from collisions. Stranding and fires have a great deal to do with the losses, and no practicable number of bulkheads will prevent a vessel going ashore and damaging the bottom sometimes fore and aft. The greater number of bulkheads might at times give more time for saving life, and also increase the facility for salving the ship after the storm had subsided. Then, as to the alleged absence of the necessary courage to open sluices or valves to balance a leak by collision on the opposite side and end to the damage, he was not prepared to admit that either. He believed there was as much pluck and courage in the average sea-going Britisher of the present day as would suffice to supply the need for someone to

stand in the breach and dare the risk. Of course, in this case, judgment, as well as courage, is necessary. It could not be denied that unfortunately for some time lately the events occurring in the mercantile marine did not tend to raise the general tone of the sea-going *employés*. There was a very keen appreciation of their rights, but very little was said about duty or responsibility. Still, there was reason to believe that a better understanding and a more cordial co-operation between shipowner, officers, and seamen would ere long be come to, and that was a state of things more necessary to be brought about than even the very important one of bulkheads, but this by the way. The central longitudinal bulkhead, as had well been said, had the formidable objection of causing a heavy list in the event of perforation of one of the compartments, especially towards midships. Looking somewhat ahead, and assuming that vessels considerably larger and more powerful than any at present afloat would be built for the Atlantic ferry, the difficulty could be got over by fitting two longitudinal bulkheads. This could well be done in a vessel having three sets of engines, and, say, four boilers in the ship, the longitudinals passing inside the wing boilers, leaving the two midship boilers in a common compartment. This arrangement would to a large extent do away with the dangerous heeling when each compartment was open to the centre line of vessel, but was, of course, only practicable in a very large class of vessel. Still, the speaker felt that these remarks only touched, as it were, the fringe of the subject, and he found it impossible to speak to the purpose without further consideration. Generally, in the paper, the subject of bulkheads was very fully, explicitly, and ably handled, and it was not at all unlikely that some legislation will ensue on the subject of bulkheads in the not distant future. Now, personally, he believed it would be desirable, first, that our law-makers and their advisers should draw up their proposals and submit them for consideration to the mercantile community. Then after the suggested alterations, amendments, or improvements had been somewhat harmonised by a representative committee, our Government should influence or persuade the other principal maritime powers to adopt something similar to what had been indicated by Mr. Hök and approved by those concerned, the difficulties of stowage would be somewhat equalised in the case of new vessels building or about to be built after the promulgation of the new rules or laws. There still remained the question of old vessels, and it would be a very serious matter indeed for shipowners to introduce additional bulkheads, hatches, winches, ventilation, etc., into the bulk of the present mercantile fleet, and this

pointed to the necessity of exercising caution and the giving of ample notice of the alterations, as the aggregate cost would be enormous and could by no means be considered lightly on such an apparently easy matter as dealing with boats and life-belts. He would only further say that the paper now under consideration was a very important and valuable one, and he hoped its importance would be duly recognised by those to whom this matter of bulkheads was referred for their consideration and report.

Mr. JAMES THOMSON, Jun., said he was not prepared to discuss the paper without further consideration. It was a very important paper, and careful study would be required before one could venture on criticism. He noted a few points when Mr. Hök was reading his paper, one or two of which had been touched on by Mr. Macoll, so he need not repeat them. On the question of a longitudinal bulkhead he thought that Mr. Hök was quite right in saying that if a ship got into collision, and was listing over a great deal, no captain would venture to experiment with his ship by filling other compartments with water. The risk of destroying his ship would be too great. He thought that in the paper Mr. Hök had rather underestimated the chance of a ship being struck on a bulkhead, and so having two compartments opened to the sea; but it must be admitted that to make a ship unsinkable with two compartments damaged would require so many bulkheads as to be, in most cases, practically impossible. He would like to refer to a matter that Mr. Hök had touched upon, that was the strength of bulkheads. He thought bulkheads were almost always not strong enough. He was sure if they were subjected to water pressure they would frequently burst, especially after the deterioration of a few years' use. In cases where they read of a ship being damaged, and a considerable amount of water coming on the bulkheads, they generally noticed that the captain seemed afraid of the strength of his bulkheads, and shored them up. It would be very desirable to test the bulkheads when possible, but this was usually not practicable. He agreed with Mr. Hök as to the advantages that could be got by shifting the fore-peak bulkhead further aft. In most cargo ships he had seen the foremost cargo space was generally larger than was necessary. As the cargo capacity was greater than the amount of dead-weight the ship was able to carry, the forward space was usually left partly filled. Thus by shifting the peak bulkhead aft the capacity of the ship would not really be reduced at all, and the ship would be made safer. He was glad to see that Bureau Veritas gave a special mark to sailing ships provided with bulkheads. He thought if the registry societies—Bureau Veritas and Lloyd's—would give some special mark to ships efficiently subdivided it ought to make a difference

in insurance rates, and tend to encourage shipowners to bring about the necessary subdivision. The calculations of the mathematical part of the paper he had not had time to look into, but he could see that Mr. Hök must have spent a great amount of labour in preparing the paper, and he thought the Institution was much indebted to him for it.

The PAST-PRESIDENT thought Mr. Hök would fully appreciate the difficulty gentlemen had in criticising the paper so soon after being read. There were just one or two points he had noted. He quite agreed with Mr. Hök on the question of longitudinal bulkheads, for they could be of little or no value if it were necessary to have valves or other means of letting the water through to right the vessel in case of collision. As regards the transverse bulkheads, these are probably sufficiently strong as now constructed, seeing that when the vessel is loaded they are partly supported by the cargo, and when light that the water would not rise to a sufficient height to unduly strain them. The assumptions made by Mr. Hök also struck him as being reasonable under the circumstances. Of course, in a matter of this sort a great many assumptions must be made in dealing with the subject generally. In dealing with any particular vessel special calculations could of course be made, and the assumptions to a considerable extent be done away with. There was one point he was rather pleased to see. He had had a great partiality for spar-deck steamers for many years, and according to Table XIV., page 349, spar-decked were evidently the least sinkable of all types of steamers. This was accounted for by their having a greater amount of freeboard to the bulkhead-deck than other types. If awning-decked steamers had their bulkheads run up to the awning-deck, instead of only to the main-deck, they would be safer even than the spar-decked steamers; but the rules did not require that. The "moral philosophy" part of the paper Mr. Macoll rather objected to he supposed referred to page 348 and the loss to insurance companies, etc. He could not subscribe to that part. The proportion of ships lost by collision was so comparatively small to the total number of vessels built that he did not think any shipbuilder in existence would object to fit additional bulkheads lest the number of losses should be reduced. He hoped that they all took a much higher view of the great responsibilities resting upon them. He thought, too, it was the interest of the insurance companies to reduce the loss, even although they got smaller premiums. He hoped that this paper and valuable Appendices would be carefully studied before the next meeting, so as to enable members to take an active part in the discussion then to take place.

The discussion was adjourned, and the meeting dissolved.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

TENTH GENERAL MEETING OF THE SESSION, HELD IN THE ATHENÆUM, WEST HARTLEPOOL, ON SATURDAY EVENING, APRIL 25TH, 1891.

WIGHAM RICHARDSON, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in Sunderland, on April 10th, which were approved by the members present, and signed by the President.

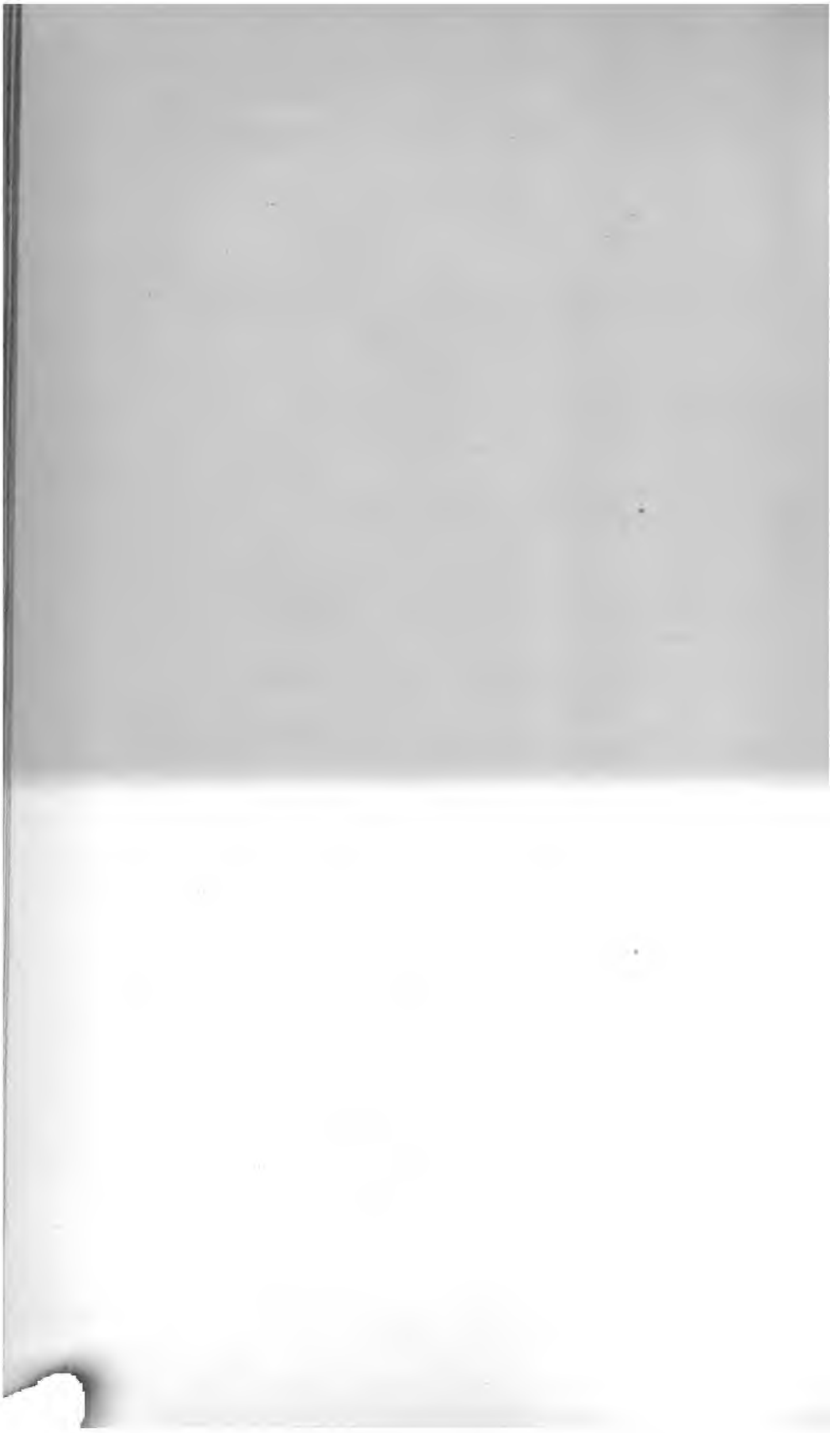
INVITATION FROM THE WEARDALE COMPANY.

The PRESIDENT said he had to inform the meeting that the Institution had received an invitation from Messrs. The Weardale Iron and Coal Company to visit their works. It had been cordially accepted by the Council, and the day fixed for Wednesday, June 3rd. He had no doubt that those having time to go would find it a very interesting occasion.

The discussion on Mr. W. Hök's second paper on "The Unsinkability of Cargo-carrying Vessels" was resumed.

Mr. HARRY GRAY read a paper on "Water-gauge Fittings for Steam Boilers," which was followed by a discussion.

Mr. J. Petree's paper on "The Basis of Ships' Scantlings" was read and discussed.



ADJOURNED DISCUSSION ON MR. W. HÖK'S SECOND PAPER ON "THE UNSINKABILITY OF CARGO-CARRYING VESSELS."

The PRESIDENT was sure they would all agree with him in regretting that they had not the presence and assistance that evening of the eminent shipbuilder of this port, Sir William Gray. It would have been an acquisition to have his contribution on the subject of Mr. Hök's paper, but he was unavoidably absent. They must try to replace him as well as they could.

Mr. A. MCGLASHAN, opening the discussion, said, the paper was a very interesting and valuable one, and, from a naval architect's point of view, he thought it had been very creditably put forth; but he must confess he was not prepared to give his own opinion at present, as he had not quite made up his mind what to say on the subject. If it was their wish, however, he would try to collect a few thoughts and express them? Well, the writer assumed that a ship would be unsinkable if, injured and having one compartment put into communication with the sea, she continued to float at a certain draught of water, which would be found to leave a small reserve of buoyancy. But he (Mr. McGlashan) expected that if they had these conditions in actual ships, they would find, in some types, with the subdivision proposed, the compartments would be so small that there would be more danger of a bulkhead being injured, in case of collision, than the writer admitted; for any serious damage being inflicted within a few feet of a bulkhead, would, to some extent, destroy its tightness, and then two compartments would be open to the sea instead of one, with the result that the ship would sink. He therefore thought that before they could proclaim ships to be practically unsinkable they would require to provide such subdivision as would enable them to sail some distance, in moderate weather, with two compartments open to the sea. Then to provide the necessary strength of bulkheads, so as to ensure water-tightness under pressure, would add considerably to their weight, and, together with the extra bulkheads required by the conditions laid down in the paper, even if these were sufficient, would add very considerably to the weight and cost of the ship. Water-tight doors in bulkheads, too,

would have to be dealt with in connection with the subject of the paper. Take the ordinary cargo ship, having the water-tight bulkhead forward of the boiler room, fitted with sliding doors, for the purpose of passing coal from bunkers in the main-hold. It will be seen that the closing of these doors could not always be readily effected, owing to various causes, such as the openings being partly blocked with coal, and so they might be left open when one of the compartments with which they communicated was injured, and then two compartments would fill with water; therefore the bulkheads must be without doors, in order to have unsinkable ships. There could be no doubt as to the desirability of carrying bulkheads higher than they were in many ships, the deficiencies in that respect were clearly shown in the paper. Bulkheads frequently terminated just at the place where they would become most useful in case of a collision. He (Mr. McGlashan) did not think that it had been quite clearly proved that the advantages which were expected to result from the adoption of the requirements laid down in the paper would follow in fact. At the end of the paper it was claimed that there would be considerable advantages to everybody, and no great disadvantage to any one, and he dared say that from a naval architect's point of view, it looked all right, but in practice it was very different. Ships yet to be built would have to go into competition with those already built. Was it proposed to make the requirements of the paper retrospective, and alter existing ships? If not, were new ships to be built to comply with these requirements, and so be handicapped in working with ships already built? He thought it would be desirable to have a plan of the arrangement of some ship actually before them, showing the conditions required by the writer, with an estimate of their probable cost, to enable shipowners and others to judge of their value. The paper did credit to the writer, but he believed it only, as it were, touched the fringe of a great subject; for instance, the subject of tonnage comes into play on almost every hand. There are many ships having large, strong erections, which, if closed with water-tight bulkheads at each end, would add greatly to the safety of the ships, but they have these erections open-ended, simply to prevent them being added to the tonnage. Then ships might easily, without much disadvantage, be built with greater freeboard and of rather lighter construction in proportion, but for the increase of tonnage. The spar-decker appeared in the paper as almost the ideal ship, and if it were not to avoid increased tonnage, many ships would have loftier sides than they have, because the sides could be easily carried up strong enough to keep out the sea under the conditions named in the paper, and more readily

secure unsinkability. But according to the tonnage laws this would add to the tonnage, and so to the expense of working the ship. In many other ways there was difficulty found in pursuing the path marked out in the paper; but he must say the paper put forward in a clear and able way present deficiencies. He thought the writer of the paper had hardly proved that bulkheads are not fitted to provide strength. They are at least utilised for that purpose. Lloyd's require them in the after-holds of raised quarter-decked ships of a certain size, when no lower tier of beams is fitted, but not if these beams are fitted. Now, apart from strength, in this case, the requirements should be the same. Neither is it quite clear that bulkheads are not fitted as partitions, for when steamers were first constructed it was found necessary to partition off the machinery space from the rest of the ship. But the facility with which iron bulkheads could be made water-tight, suggested the advisability of making them so, in order to secure the evident advantage of water-tight subdivision. It is averred in the paper that the real cause of their being fitted is to provide safety to property and lives at sea, but it is doubtful if water-tight subdivision would have become common to the extent it has in cargo ships if the working of the ships had not required bulkheads. He very heartily expressed his appreciation of the paper, and, while making these remarks, it was only with the view of pointing out matters which might require further consideration.

Mr. F. YEOMAN did not know that he could properly discuss the paper, because it was of a highly technical character. He, however, thoroughly endorsed the remarks of Mr. McGlashan that it was at least on the high road to an exceedingly good object, namely, the unsinkability of ships. In view of a suggested insurance scheme for seamen, he had recently got out certain statistics as to the life-loss in connection with the mercantile marine of the United Kingdom, and thought it might be interesting to give a few details as having a bearing upon the subject under discussion. He took it that the object of the writer was twofold—first, the all-important one of lessening the life lost; and second, the saving of property, mainly as affected by collisions. It was on the loss of life that he wanted to give a few figures. The gross life-loss (crew) from merchant vessels of the United Kingdom in the last tabulated year was 2,847 lives. They were divided into three classes, easily remembered, viz., (1) from wrecks of, or casualties to, the vessel, 962 lives; (2) from accidents other than by wreck of, or casualty to, the vessel, 840 lives; (3) disease, murder, homicide, suicide, and unknown causes, 1,044 lives; making the total of 2,847. 2,010 of these losses happened at sea, and

837 in rivers and harbours. Before the Royal Commission on Loss of Life at Sea, it would be remembered, as compared with men employed, sailing vessels were found to have lost double the lives of steam vessels. As pertaining to collisions, Board of Trade statistics were exceedingly interesting. The average annual life-loss for the past three years from total losses of vessels under this heading was 124, viz., 54 in sailing vessels and 70 in steamers. The point he wanted to make was that as compared with the full total of 2,847 lives lost during the year, the loss from collisions did not seem to be so serious as might be supposed. He might state in passing that in the last year two steamers were lost, one with 51 lives and the other 47; but the annual average for steam and sail for the last three years was 124. It would be borne in mind that their shipping trade was done either under home trade, or foreign articles of agreement; the former embracing all coasting and home trading between the Elbe and Brest, the latter all trading beyond those limits. It was a most remarkable fact that last year the whole home trade United Kingdom steamship fleet performed this service for the loss of but one single life under this heading. These vessels make sixty or seventy voyages in the year from such ports as the Tyne or Hartlepool to London and elsewhere; or at a fair estimate, have an average steaming by each of something like 35,000 to 40,000 miles per annum. He thought that said very much indeed for the rigid care and ever-present anxiety with which the steamers in the mercantile marine must be navigated. Similarly, the United Kingdom merchant sailing ship fleet in the same home trade, or to collisions, were only responsible for six lives, or seven lives in the aggregate of the home trade for the whole year in both sail and steam! Perhaps it was but natural that in the consideration of such a question the general public, and even this meeting, would have in view such losses as that of the "Utopia" at Gibraltar, involving hundreds of lives. That was indeed a sad occurrence, but might they not be compelled to look upon it somewhat in the same category, say, as a Tay Bridge accident upon the railway? As long as they had traffic on land and sea, it was to be feared such exceptional accidents would now and again happen, having to rely upon fallible men and possibly failing machinery. Considering the conduct of their trade as a whole, in face of such a record as that just alluded to, he thought they would be bound to admit that it was exceedingly well done. The question of the subdivision of steamers was a most important one, and as to whether passenger steamers ought to be allowed to proceed to sea, as he saw in the newspapers the other day, with upwards of 1,400 lives on board

without some such provision being made, he was not quite sure. He did not know any more important question could engage the attention of this Institution. One more remark and he was finished. Some of the gentlemen present came from the Tyne ports, and had seen various phases of shipping. Some of them who had had sailing ship experiences were a little afraid lest they might unnecessarily interfere with the commercial aspect of their steam shipping. Perhaps they might be compelled to risk some little danger, the remedying of which might be uncertain, rather than interfere with vital trading conditions of their mercantile marine. He himself remembered about 250 sailing ships being registered as belonging to Hartlepool; now there were less than a dozen. He was further confronted with the fact that during the last year only 10 British sailing vessels cleared from the Hartlepools, with cargo to foreign ports or British possessions, but no fewer than 588 foreign ships so cleared in the same period. He was just a little timid, perhaps, as to whether there was not a chance of such a condition of things being brought about in steam shipping. The *Newcastle Daily Chronicle* often asked the question as to how foreigners worked steamers that Englishmen could not sail? It was perfectly clear. He had had occasion the other day to note the wages of a new foreign steamer, and found they were 40 per cent. less than that of a British vessel of the same size. Again, they had the load-line, as to which the foreigners run perfectly free. Under the Merchant Shipping Act, 1876, sailing from United Kingdom ports they are amenable, but in practice they are not interfered with by the Board of Trade detaining officers, although, by comparison, loading much deeper. These were facts the English shipowner had to face. From the Tyne 4,227 British and 1,664 foreign steamers cleared in 1889. From Sunderland 808 British and 489 foreign steamers, no inconsiderable factor in trading from either port. The clearances from the whole of the United Kingdom in that year, of sailing ships were:—British, 5,439; foreign, 10,695. Steamers—British, 29,213; foreign, 9,198; total, 38,411. It might be urged that foreign steamers were of comparatively small size; but whilst the similar sized British were running under heavy restrictions, the foreigners were running perfectly free of such restrictions.

The PRESIDENT—Can you say what additional percentage a steamer not under the Board of Trade restrictions as to load-line may carry?

Mr. YEOMAN—If you take one of our ordinary steamers, built in 1882-83, sold to a foreigner, she will carry 100 to 140 tons more cargo.

The PRESIDENT—What additional percentage would that be—10 per cent?

Mr. YEOMAN—Not quite 10 per cent., but he should think at least 7 per cent.; this carrying of course, important at any time, but all important in times of depression, when British steamers were not only not making money, but were actually running at a loss. He knew of steamers owned in that port, which, from being new, were marked at about 1 foot 6 inches, having always sailed safely. They were now officially marked at about 1 foot 11 inches in summer and 2 feet 2 inches in winter. That represented at least 100 tons, whilst he did not think the foreigner would stop where the Englishman would to-day voluntarily do so. He trusted the commercial aspect and necessity of their steam shipping in those days of hard competition would not be lost sight of in the further discussion of this very valuable paper.

Mr. W. MENZIES observed, in regard to what the last speaker had said with respect to the draught of foreign ships in comparison with English old ships, that sometime since he was superintending the building of steamers for a foreign owner. Lloyd's mark was put on them to carry 1,800 tons. The vessels left to be loaded at a neighbouring port, and on the way round Lloyd's mark was taken off, and the vessel actually loaded 2,200 tons.

The PRESIDENT—That would be over 23 per cent.?

Mr. MENZIES—Something like that. If this is thought an exaggeration I can call upon some gentlemen who are present to corroborate the statement.

Mr. MUDD said he happened to engine these vessels—four of them. He might say they burnt a couple of tons of coal per day more than they were expected in comparison with similar vessels. When they investigated the matter they found it was the heavy cargo that was doing it.

On the motion of Mr. FOTHERGILL, seconded by Mr. MACOLL, the discussion was further adjourned, the PRESIDENT remarking that the question of load-line naturally arose on Mr. Petree's paper on "The Basis of Ships' Scantlings."

WATER-GAUGE FITTINGS FOR STEAM BOILERS.

By HARRY GRAY.

[Read before the Institution in West Hartlepool, April 25th, 1891.]

In all details of the steam engine, strength and simplicity, combined with efficiency, are the chief aims of the engineer; and in dealing with the steam boiler the same requirements are necessary. Strength, to withstand the strains of the working pressure; simplicity, so that opportunities for accident may be lessened, and facilities for examination and repairs increased; every detail contributing to the efficient working of the boiler.

The steam engine without the boiler is useless; hence the boiler, with its attachments, demands our careful and constant attention.

The various details of construction received in days gone by a most minute consideration, resulting in an almost complete exemption from failure from this source; but at the present time, with the high and increasing working pressures, other sources of danger have become intensified, especially "shortness of water through a false indication of the water-level by the water-gauge." The glass water-gauge affords the simplest and most accurate means of "showing" the level of the water in the boiler, and is that generally used for that purpose.

In the steam boilers of the Egyptians, 200 B.C., as in those of the pioneers in steam of the twelfth and sixteenth centuries, the water-level was not a source of much trouble, as it was maintained by gravitation, a tank placed either beside or above the boiler with a pipe leading from one to the other. At this time steam was used only as a means of producing a partial vacuum to allow the atmospheric pressure to come into force, hence little or no pressure was employed in the boilers above that of the atmosphere. But with the rise of working pressure the system of supplying the feed-water through a pipe without any means of preventing the pressure overcoming the head of water in the feed tank was a source of trouble necessitating the employment of other means for feeding the boiler. Thus, about the end of the seventeenth and the beginning of the eighteenth centuries we find Savory employing gauge cocks, fitted on the side of the boiler, one above and one below the desired water-level, or placed on the top of the boiler, with internal pipes terminating at different levels.

Gauge cocks seem to have been in general use from this time, but it was not until steam was used directly as a motive power that the working pressure was raised to such an extent as to draw the attention of engineers to the importance of the water-level in the boiler. At this time James Watt's inventive mind conceived the idea of connecting two gauge cocks by a glass tube, and in about 1780 there appears the first record of the glass tube water-gauge. Fig. 3, Plate XLIX., is an enlarged reproduction of a print of this gauge. The experience of to-day confirms the necessity of having this or some other means of accurately indicating the position of the water-level at all times, and under all circumstances. It is, in fact, essential to the safe working of the steam boiler.

In Seaton's *Manual of Engineering* the position of the gauge glass is arrived at by allowing $\frac{3}{10}$ths of an inch per foot diameter of the boiler between the combustion chamber tops, or highest point of heating surface, and the lowest water-level visible in the glass. But in the case of boilers in steamships and other floating vessels, variations in the draught between the fore and after ends, as well as "listing" of the vessel, affects the relation of the water-level in the boiler to the highest point of the heating surface. The following tables give the variation of the water-level in the boiler per foot variation of the trim of the ship, the length of the water-level being taken as from the glass of the water-gauge to its opposite extreme in the boiler. Consequently, the further the glass is removed from the boiler the greater the variation.

TABLE A.

VARIATIONS BY ALTERATION OF DRAUGHT AT FORE AND AFTER ENDS OF VESSELS.

Length of Ship in Feet.	FORE AND AFT VARIATION OF	
	Draught of Ship.	Water in Boiler.
100	1 foot	·12 inches per foot.
150	1 ,,	·08 ,, ,,
200	1 ,,	·06 ,, ,,
250	1 ,,	·048 ,, ,,
300	1 ,,	·04 ,, ,,
400	1 ,,	·03 ,, ,,

TABLE B.

VARIATION BY "LIST" OF VESSEL.

Breadth of Ship in Feet.	VARIATION OF	
	List of Ship.	Water in Boiler.
30	1 foot	·4 inch per foot.
35	1 „	·35 „ „
40	1 „	·3 „ „
45	1 „	·26 „ „

As an example, a ship 250 feet long proceeded to sea 12 feet by the stern. The water-level from the gauge glass to the extreme end of the boiler being 18 feet, therefore $12 \times 18 \times \cdot048 = 10\cdot3$ inches was the difference between the water-level in the boiler and the water-level when the ship was on an even keel. Therefore $10\frac{1}{4}$ inches of water in the gauge glass on the after end of the boiler would be the lowest safe water-level.

Again, a ship 35 feet beam has 3 feet list, she has two boilers 13 feet diameter placed fore and aft, with a water-level 11 feet across. Here $11 \times 3 \times \cdot35 = 11\cdot55$ inches variation. The gauge glass being placed on the centre line of the boiler, $11\cdot55 \div 2 = 5\cdot77$, or $5\frac{3}{4}$ inches of water in the gauge glass to maintain the least amount of water over the wing tubes and combustion chamber tops compatible with safety.

These facts show that in placing the water-gauges on boilers in steamships, due allowance should be made with regard to the average trim of the ship, both load and light, especially in vessels with the boilers right aft, in consequence of their being so much by the stern when in ballast. When the gauge glass is at the fore end, this evil is avoided, as that is the lowest point of the water-level. In order to avoid exposing the wing tubes and combustion chamber tops through a list of the vessel, which tends to cause leaky tube ends, if not collapse, the practice of sloping the rows of tubes in the wing boxes should be encouraged.

Glass water-gauge mountings are fitted in two ways to the boiler, either direct on to the shell or end plate, or else mounted on a standard of cast iron or brass, being either screwed in or jointed with a flange and studs.

When the gauges are placed direct on the boiler, internal pipes should be fitted, that leading to the water space terminating in some part

unaffected by the ebullition of the water, and that to the steam space, so as to be unaffected by any rush of steam through the steam dome necks, or the stop and safety valves, which would tend to reduce the pressure above the water in the gauge glass, producing a false water-level higher than it really is in the boiler. All internal pipes should be not less than 1 inch or $1\frac{1}{4}$ inches diameter, and free from all bends likely to encourage the deposit of mud or scum, or to prevent the free passage of steam or water.

When the gauges are placed on standards, and connected to the steam and water spaces of the boiler by external pipes, shut-off valves or cocks being fitted between them and the boiler, opportunities are afforded for examining and repairing the pipes and water-gauge mountings whilst the boiler is under steam (Figs. 1 and 2, Plate XLVIII.). In such an arrangement there must be only one communication between the steam and water spaces, and that must be through the gauge glass itself, a hollow standard affording a communication between the steam and water spaces, independent of the gauge glass, renders the water-level in the glass less sensitive, and makes the testing of the passages and gauge glass more complicated. This has been a frequent source of disaster. Whilst the placing of the test cocks on the hollow standard renders them absolutely useless, as affording no reliable test of the water-level, without a means be provided of readily proving whether the top and bottom cocks and pipes are clear.

In December, 1889, the combustion chamber tops of the S.S. "Albion" were brought down by shortness of water, although at the time of the explosion the water was showing more than full glass in the gauge, and all the three test cocks showed water. In this case the water-gauge mountings, as well as the test cocks, were fitted on a hollow standard. Examination showed that the steam pipe had become choked, probably by the scum on the surface of the water being lifted into it when priming took place. On account of this obstruction in the pipe the pressure above the water in the gauge glass and standard was gradually reduced, and the water-level in both gradually rose. The engineers failed to carry out a thorough test of all the passages, and were deceived by the test cocks and by the gauge glass. Trusting to appearances, the real water-level in the boiler was allowed to become lower and lower, until they found there was something wrong in the combustion chambers, which were found to have collapsed. Had the test cocks been on the boiler, the water-level in the gauge glass would have been shown as false. Had there been no hollow standard, the

simple test of the gauge glass mountings would have shown no blow through from the steam. The complicated double shut-off of the gauge glass mountings and the boiler shut-off cocks was not resorted to. Simplicity is the best safeguard against want of knowledge or want of thought on the part of those in charge. Even when the complete test has been applied, omission in not re-opening some of the shut-off cocks, especially those on the steam side, is another cause of trouble, resulting in a false water-level, as in the case of the pipe becoming choked. This was shown to have been the cause of the explosion of the boiler on board the S.S. "Colina," in May, 1890, where the valve on the boiler end of the steam connection was not re-opened after testing. The same omission is reported to have taken place lately on board H.M.S. "Orontes," resulting in the disabling of the boiler.

In all glass water-gauges the greatest danger lies in the possibility of their showing a "false water-level," by which those in charge may be deceived unless they are always on their guard. In some cases this defect is more likely to occur than in others, through defective leads of the pipes and impurities in the water in the boiler. When the pipes are lead horizontally, or are bent down and then up again, opportunities for the deposit of mud, scum, and the like, are afforded, and a drop or syphon bend in the steam connection has been known to form a water-trap, resulting in a false water-level through the steam being condensed until the water so produced caused a reduction of the pressure above the water in the glass, which consequently rose above the true level of the water in the boiler. The stoppage of the water connection is of rare occurrence on boilers on board of steamships, as the absence of the water from the gauge glass, after even the simplest test, at once gives warning that something is wrong; but the partial stoppage, preventing the free motion of the water, is frequently the cause of an undue steadiness of the water in the gauge glass. The stoppage of the steam connection is the most common cause of false water-level, and, as shown in the cases of the S.S "Albion," S.S. "Colina," and others, leads to the most disastrous results. Priming is the general cause of stoppage in these cases, the scum being lifted from the water at such times is deposited everywhere, part being carried into the steam pipe connection to the gauge glass, the pipe becomes gradually choked, its area being reduced from time to time, until finally it is closed up; meanwhile the pressure above the water in the gauge glass has been gradually reduced, the water-level as shown in it has also risen above its true position, a full glass and more being the final result, as in the cases mentioned. Upon the true realisation of the facts of such

a case the safety of the boiler depends. If the engineer is misled, and blows the water in the boiler down, an explosion is sure to follow; if he lets the water alone, he may expect the same result at any moment, unless he at once proceeds to find out by thoroughly testing the true water-level. Under the best circumstances this is too often a long and unpleasant task, entailing a lot of climbing about; consequently it is not made use of as often as it should be, if it is done at all. Again, when priming occurs the engineers are generally kept busy attending to the engines, and have but little time for such a test; hence the necessity for some means by which the thorough and complete test of the whole of the water-gauge connections may be simplified, and by which it shall be impossible to apply any partial or incomplete test. Figs. 1 and 2, Plate XLVIII., represent two methods of testing the water-gauge and all its connections without closing any of the valves or cocks connected with the gauge glass except the one fitted between the boiler and the pipe leading from the water space, which are being introduced by Messrs. Smith Bros. & Co., of Nottingham. In Fig. 1, Plate XLVIII., this result is effected by a cock (Fig. 4, Plate XLIX.), having two passages through the plug, each independent of the other, one being horizontal, and the other vertical from the side down through the bottom of the plug. This mode of construction protects the surface of the plug, and also the shell of the cock from the action of the water and any impurities contained in it, as under the ordinary conditions the horizontal passage is open. Its action is simple and complete, one-quarter turn in either direction closing the passage on the one side, and on the other opening communication by the vertical passage in the plug to the atmosphere. Consequently, by alternately turning it a quarter of a turn in each direction all the passages from the steam and water spaces are blown through alternately, and a complete test is applied. In Fig. 2, Plate XLVIII., the same result is obtained by a valve arrangement, consisting of two small valves fitted one on each side of the main valve (Fig. 5, Plate XLIX.), so that when the communication is divided by closing the main valve all the passages of the water-gauge can be blown through from the steam and water spaces by opening the small test valves.

When the water-gauge mountings are fitted direct to the boiler the same liability to their becoming choked has to be contended with, and they are also subjected, too frequently, to a simple blow through, instead of the double shut-off test. One arrangement to ensure such a test being always applied is shown in Fig. 6, Plate L., of similar construction to Fig. 4, Plate XLIX., by which the steam and water passages can only be

tested alternately independent of the steam shut-off cock, by one-quarter turn each way.

The breaking of the gauge glass is a frequent source of trouble, and the flying pieces of glass and scalding water upon such occasions have proved such a source of danger to those near, that with the high boiler pressure of the present day this may account for the tendency of those in charge not to test the gauge glass if they can possibly avoid doing so. The cause of such breakage is certainly not the pressure itself, as official tests have been made, and 3,500 lbs. per square inch have been applied to the gauge glasses without producing fracture. A stronger force is present under the working conditions of gauge glasses on steam boilers, and the higher the pressure the greater is such action, namely, contraction and expansion, exerting a power that is capable of causing fracture even in the strongest metals, much less in the case of such a brittle substance as glass. It has always been the aim of engineers to make allowance for the expansion and contraction of metal, but in gauge glasses this rule would seem to have been neglected, the only provision made being to prevent any injury to those in charge through the breakage of the gauge glass. The plan usually adopted has been to fit long rods to the cock handles, using the latter as a crank, enabling the engineer to work the cocks without approaching close to the glass. But the loss of power in proportion as the long handle and the crank or short handle approach the dead centre, requires such extra force being applied that perfect control is lost, resulting often in a sudden closing or opening of the cock, bringing such a shock to the gauge glass as to cause it to break. Another way is to place a ball or mushroom valve in the passages of the water-gauge mountings, which shall be actuated by the rush of steam or water upon the breakage of the glass, closing the passage.

For this class of automatic water-gauges 150 patents have been applied for during the last fifteen years, 60 per cent. of which have been carried through, and not half a dozen of them are in use at the present day. Most of these have failed under the working conditions, the automatic valve becoming set-fast or acting when not required, and remaining shut, or else being the cause of the passage itself becoming choked by mud, etc. Only two have met with any favour, namely, Dewrance's and Hopkinson's.

Fig. 7, Plate L., shows in section the construction of Messrs. Dewrance's, of London, provision for the automatic closing of both steam and water passages being made. In the upper mounting a ball valve is placed in a cage, which forms one piece with the top screw plug, the cage fitting closely around its top edge into the mounting, the steam passing

through two openings in the cage itself, a large hole at the side forms the seat into which the ball valve is forced by the rush of steam upon the breakage of the glass, whilst steam passes in a smaller quantity through the small hole at the bottom until the shut-off cock is closed. In the lower mounting the ball valve is held underneath the opening to the glass in a cup-like arm, so constructed that it can only be put in the one way, which is secured by a plug cap. In this case the ball valve is lifted bodily up into the opening above it leading to the glass, thereby preventing the further escape of water.

Figs. 8 and 9, Plate LI., show in section two forms of the automatic gauge of Messrs. Hopkinson, of Huddersfield, in which no provision is made for the automatic closing of the steam passage, it being allowed an unimpeded blow through. In the lower mounting a mushroom valve is placed under the opening to the gauge glass, being placed on a cage screwed into the mounting (Fig. 8), or attached to the end of the lower drain cock (Fig. 9). The spindle of the valve projects through the top of the cage, over which a phosphor-bronze spring is placed, and secured by a nut on the end of the spindle. Upon the breakage of the glass, the rush of water acting upon the projecting edge of the valve closes it (Fig. 8), but upon the pressure being removed, the spring ensures the re-opening of the automatic valve, and also prevents its closing again, except upon the rush of water consequent upon the fracture of the gauge glass.

Another means employed by some to stop the wholesale dispersion of the pieces of the broken glass and the scalding water, is to enclose the glass in a brass tube having slots at opposite sides to enable the water to be seen; whilst others employ a shield of wire gauze, or plate glass of a triangular or horse-shoe section enclosing the glass on the front and sides, and leaving the side towards the boiler open. These shields also prove a most useful protection to the glass from any external cooling influence, such as cold air from the ventilators or sprays of water from the deck. But none of these appliances afford any protection to the gauge glass from the main causes which tend to its breaking, namely, contraction and expansion from inside influences.

Under ordinary working conditions the water-gauge glass upon a boiler working at a pressure of 160 lbs. per square inch is subjected to a temperature of 370 degs. Fah. When the drain cock upon the lower mounting is opened in order to blow through to test the water-level, the pressure in the glass is removed, and the temperature is likewise reduced in proportion, as in the case of steam the pressure and the temperature

are dependent upon each other. Allowing for the heat transmitted to the glass by the passing steam, the temperature of the glass is suddenly reduced from 370 degs. Fah. to about 240 degs. Fah., and as suddenly raised again upon the pressure being put upon the glass when the drain cock is closed. This action is most clearly shown when fitting a new gauge glass when steam is on the boiler. Before putting the boiler pressure on the glass, steam is allowed to blow through it, in order to warm it, after which the drain is shut, and the pressure thus put on the glass raises its temperature to that of the steam. It is then that the glass breaks, in the majority of cases, and not before the pressure is put on; and as the pressure itself cannot be the cause, the sudden increase of temperature, consequent upon increase of pressure causing the sudden expansion of the glass, must, in the writer's opinion, be the cause of its breaking.

To avoid the reduction of pressure in the gauge glass when testing the water-level is a most important point, especially with the high working pressure of the present day. A drain valve loaded with a spring to about 20 lbs. below the boiler pressure is shown in Fig. 10, Plate LII., and also in Fig. 5, Plate XLIX., and Fig. 6, Plate L., by means of which the variation of pressure in the gauge glass is reduced to 20 lbs., with a variation of temperature of only 10 degs., with a boiler pressure of 160 lbs. In order to keep the valve shut a spindle is attached to it by a horse-shoe connection, sufficient depth being allowed for the foot of the spindle in the horse-shoe to permit of its being released from the valve without opening it, this being effected by the boiler pressure compressing the spring.

The gauge glass is also liable to fracture at times when it has not been recently tested, either from outside or inside influences. When the water in the lower or water connections has been allowed to stand for any length of time it becomes cold, and consequently the pipes and connections and the lower part of the glass become cold also. Only the surface of the water in the glass remains heated by contact with the steam, the lower part of the glass being subject to a temperature of 220 degs. Fah. or less, and the upper part is subject to a temperature of 370 degs. Fah., the glass being under a strain of unequal expansion, due to the variation of temperature of 150 degs. or more between its upper and lower ends.

The cooling of the water connection between the gauge glass and the boiler also produces a false water-level in the gauge glass, lower than that in the boiler itself, consequent upon the increased density with diminished volume of the water upon its becoming cold in the pipe and still being

under an equilibrium of pressure with the water in the boiler. Taking, for example, the water exposed to cooling in Fig. 1, Plate XLVIII., as 5 feet in height, the pressure being 160 lbs. per square inch, the water in the boiler is at a temperature of 370 degs. Fah., its heaviness being 55·18 lbs. per cubic foot, when the water in the connection pipe to the water-gauge has cooled down to 120 degs. Fah. through not having been removed by being blown through, its heaviness having increased to 61·73 lbs. per cubic foot. Consequently, 53·4 inches of cold water in the pipe will balance the 60 inches of hot water in the boiler, and the water-level in the glass is lowered 6·6 inches.

The difficulty experienced in getting a gauge glass to stand upon replacing a broken one is often attributed to some fault in the glass itself, whereas the fault often lies in the fitting of the mountings. Where these are screwed in, instead of having a flange secured by studs, this fault is more likely to occur on account of the smaller diameter of the joint, any difference of the thickness of which at one side more than the other betrays the fact that such mounting is not perfectly square with the boiler plate in every way, consequent on the hole in the plate not being at right angles to the surface of the plate. In Fig. 12, Plate LIII., the water-gauge mountings are shown screwed into a boiler plate 1 inch thick which is supposed to be perfectly straight. The upper mounting is shown perfectly true in every direction, its centre line being at right angles to the surface of the plate. The lower mounting is not shown true, the hole having been drilled and tapped on a slant downwards in the proportion of $\frac{1}{32}$ inch to the inch, the joint of the collar of the mounting 2 inches diameter, being open in consequence $\frac{1}{16}$ of an inch at the bottom, and the mounting is therefore inclined upwards, and the vertical centre line of the mounting, which should be that of the glass, is thrown inwards towards the boiler. The centres of the top and bottom mountings being 18 inches apart, the distance from the centre of the bottom mounting to the top of the glass being 17 inches, consequently at this point the centre line of the bottom mounting is thrown out $\frac{17}{32}$ inch, or more than half an inch, simply because the hole in the boiler plate is $\frac{1}{32}$ of an inch out of truth. In order to get the glass in line with the top mounting it is brought against the front edges of the gland and gland nut, and if the clearance already provided is small, both these parts have to be filed out. It is this nipping of the glands and nuts on the surface of the gauge glass (Fig. 13, Plate LIII.) that so frequently breaks them when tightening up the glands. If, when fitting up glass water-gauge mountings in place, a steel bar turned a true fit in the glands was used to test the

centre lines of the two mountings, this trouble, resulting from bad fitting, might be avoided. In the case of the boiler of the S.S. "Gemini," fitted with Dewrance's asbestos-packed water-gauge, which exploded in 1889, the engineers broke five glasses between Cardiff and the Lizard on a voyage to London. The fourth broke whilst tightening the glands. Having no more glasses, they were reduced to two test cocks. The top one of these was set fast, and the handle bent when they tried to start it. The remaining test cock was only 1½ inches above the combustion chamber top, which collapsed upon reaching the Downs, although water showed in the test cock.

Fig. 11, Plate LII., shows a class of fittings in general use among German engineers, in which is a valve, a hollow spindle with an eccentric cap nut on the handle affords a means of examining and cleaning the passage below the valve in case of need; a coarse thread screw is employed to open the valve by half a turn or less. Test valves are constructed on the same principle, the handles being weighted so as to close the valve by their own weight on being let go.

The packing of cocks by means of asbestos forms a most important feature in water-gauges of the present day, as a means of preventing leakage taking place and ensuring the efficiency of the cocks. Fig. 4, Plate XLIX. Fig. 6, Plate L. Figs. 7, 8, 9, Plates L. and LI.

In conclusion, the writer hopes that this paper will be the means of eliciting from sea-going engineers of experience many practical remarks which will be of service to the whole profession.

DISCUSSION.

Mr. THOMAS MUDD congratulated Mr. Gray on having given them a paper on details. It seemed to him that papers on the mechanical details of engineering and shipbuilding should be encouraged as much as possible. He should not at all like to discourage the reading of theoretical or mathematical papers, or speculative papers in regard to new ideas. He did think, however, there was very great value to be attached to papers like that before them. They all knew that every individual engineer or shipbuilder had his attention particularly drawn to some detail, perhaps in the first instance merely by some accidental circumstance in his practice, and in that way he came to know more minutely about it than his neighbours. It was advantageous in institutions like this that he should have an opportunity of letting his fellows benefit thereby. He

thought every successful engineer and shipbuilder could trace his success to careful attention to details rather than to any brilliant new theory he may have struck. While he believed one should do what he could to be fully alive to any danger there might be in the apparatus he fitted, still, on the other hand, they should not exaggerate that danger, and he could not help feeling in reading this paper that some slight exaggeration of dangers had been put forth. Perhaps that arose from Mr. Gray's recollection of the fact that one had sometimes to exaggerate a danger four or fivefold before some people would see it at all, and if that was his object he had no further criticism about it; but on that particular point he (Mr. Mudd) would refer to the top of page 378, in which he states, "If the engineer is misled, and blows the water in the boiler down, *an explosion is sure to follow.*" He did not think an explosion was sure to follow—it possibly might—and very likely his boiler would be burnt and damaged, but that an explosion was sure to follow was a slight exaggeration. He happened to be one of those guilty individuals who applied the hollow standard, and he thought whilst there might be much to be said for the new method that Mr. Gray had put before them, of stopping the standard off in the middle, and leaving it only open through the glass, they must not overlook any new dangers that would bring, by the introduction of two bends in the standard, which would be liable to become choked up. Still, the plan was well worth their consideration. He thought Mr. Gray might have called attention to the very great importance of having water-gauges and fittings large enough. He had referred to the internal pipes not being less than an inch or $1\frac{1}{4}$ inches, and with as few bends as possible; but looking to the fittings he had brought before them he could scarcely be said to have stuck to the rule he had laid down, as he had introduced bends where before there were none, and with regard to the cocks he had shown in the lower fittings, they seemed to have very small and crooked passages, which might get choked by sediment. On the question of the breakage of gauge glasses, he thought there was a slight amount of confusion in the paper. At one part Mr. Gray gave them the impression that the glass under ordinary use was at its highest temperature, that it was cooled greatly by blowing steam through it, and then when they turned the water on again they would suddenly increase the temperature, and break it. Then later on he said the gauge was cooler in ordinary use, owing to the cooling of the external column of water, and when blown through they heated it up, and when the fresh water came in they broke it by again cooling. These two theories seemed opposed to each other. He was prepared to agree that the most prolific

cause of broken glasses was sudden contraction or expansion; but they should try to find out which of the two theories was the right one, as the success of their efforts to prevent it would depend on their making a true estimate of the cause. He himself was disposed to believe that the latter theory was the right one. He would also refer to the statement on page 382, where Mr. Gray had alluded to the water-level getting 6½ inches lower in the glass than the level in the boiler, due to cooling of the external column. That seemed to him an extraordinary difference of level from such a cause, and he knew of no case where the water-level had ever been suspected of being 6½ inches down due to temperature in the pipe. On the general point of the use of the open standard, he would just say that their own practice was not to use cocks at top and bottom, but valves 1½ inches in diameter with 1½ inch copper pipe, the standard having a 2 inch clear way through it. They had never known of any difficulty or danger or false water-line whatever, and he thought that immunity from trouble was due to providing sufficiently large openings in the several parts, with less liability to choking. He might just mention that he was not in favour of such an arrangement as Messrs. Dewrance's for shutting off automatically both steam and water ends when a glass broke, but only the water end; and for that purpose they had used a very large number of Hopkinson's arrangement, called Frazer's patent, which had worked admirably, and given no trouble whatever.

Mr. Tom Westgarth observed that Mr. Gray commenced his paper by saying that simplicity was one of the chief desideratum. He quite agreed with him, and thought it would be much better to do away with the various pipes, spring fittings, etc., and put nothing on the boilers but ordinary fittings seen in Fig. 10, Plate LII. (without the spring), and without any stand pipes whatever. He had known several cases of serious trouble where the long stand pipes had been fitted; he also thought the internal pipes objectionable. If the stand pipes are fitted he considered it better not to fit the cocks at connection to boiler as required by Board of Trade and Lloyd's surveyors. His practice was to fit the gauge mountings direct upon the boiler, and generally in duplicate, one placed at each side of the boiler, which got over the difficulty mentioned by Mr. Gray as to seeing the true level when the vessel had a list. Another advantage being that if one glass broke the other was left, and so the damage could be repaired calmly and quietly, and with very little trouble.

Mr. J. E. STODDART had very few words to say on the subject, as Mr. Westgarth had stated exactly what he wanted to point out concerning simplicity of construction. The author in the beginning of the paper stated that "the various details of construction received in days gone by a most minute consideration," etc. (page 373), and this he believed, but it appeared to him that there were unnecessary complications nowadays where the fittings should be most simple. The modern water-gauge fittings were sometimes made up of two or three patents when one was sufficient. It was suggested in the paper that "internal pipes should be fitted not less than 1 inch diameter when the gauges were placed direct on the boilers." Now, he was of opinion that there was nothing more dangerous than the internal pipes in connection with the water-gauge, the external pipes had their dangers, but they could be disconnected and cleaned, whereas the internal pipes could not be cleaned when the boiler was under steam. He once examined a main boiler which met with an accident at sea through the *internal* pipe at the top of the water-gauge becoming choked and showing a full and false glass of water. The engineer on the watch being anxious to know the height of the water, opened the blow-off cock and blew the water out of the bottom of the boiler until he saw the water suddenly leave the gauge glass, and the lower connection of the water-gauge being below the crowns of the furnaces, the water did not fall in the gauge glass until it had reached that dangerous level, consequently the furnaces collapsed. Another mishap, just the reverse of the former, came under his notice, which was caused by the *external* pipe, connecting the top of the water-gauge to the top of the steam chest, becoming choked. In this case the vessel had just left port, and the donkey boiler was under steam. The engineer imagined the gauge glass of the main boiler to be empty, consequently he turned steam from the donkey boiler on to the donkey engine to aid the main engines in pumping up the main boiler, and it did not dawn upon the engineer that the boiler was almost full of water until the main engines gradually stopped. So that the man was about to test the boiler by hydraulic pressure without knowing it. Then again, he had met with furnaces collapsing in consequence of there being a false glass of water when the top cock of the external gauge pipe was accidentally closed. In his opinion there was no arrangement so safe as the water-gauge fitted direct on to the boiler, having flanged cocks with large openings, about 1 inch diameter, through the plug next to the boiler, and these plugs should be fitted with handles, which could be closed automatically, or so arranged that the engineer could shut them with ease. Cocks of the ordinary type, with

openings about $\frac{3}{8}$ inch diameter through the plugs, should also be arranged at the top and bottom of the gauge glass as well as a drain cock. When this was done the water passages from the boiler into the gauge glass fittings could be tested at any time, and there could not be any signs of water in the glass when the water was below the lower gauge cock, or say 5 inches above the combustion chamber crown. In the locomotive engine the water-gauges are fitted directly on to the boiler, and they give little or no trouble, although the pressures are as high as 160 and 180 lbs. per square inch. A great deal was said about having water in the gauge glass unaffected by the ebullition of the water, but he had the water-gauges fitted direct on the boilers of two vessels, and at sea he found it a *great advantage* to know exactly what was going on at the surface of the water in each boiler. He saw on the platform a model of an automatic apparatus invented by a member of this Institution (Mr. D. B. Morison) for closing the cocks of the water-gauge when the gauge glass broke. He might say that he was present when this arrangement was tried under steam. The gauge glass was broken with a stick and the steam and water were shut off instantaneously. The great advantage of this automatic closing apparatus was that the various parts are *external* and can be seen and adjusted by the engineer at any time. In the model he believed the gauge glass fittings are attached to a standard, but the gauge glass fittings could be placed direct on the boiler, then the engineer could test at any time the water passages between the boiler and the gauge glass. Water-gauge fittings could be placed on the back end of the single-ended boiler with ease, and he knew from experience that they could be fitted on the side of the shell of the double-ended boiler without much trouble. He was therefore of opinion that water-gauges should never be fitted with internal pipes, and as seldom as possible with external pipes, as this led to a great difference between the level of the water in the boiler and that in the gauge glass.

Mr. B. G. Nichol thought the speakers had said almost all that could be said on this subject. He cordially concurred with the last two speakers, and utterly and entirely objected to all standards, and to either internal or external top or bottom pipes.

Mr. E. Hall-Brown expressed the pleasure with which he had listened to Mr. Gray's paper, and thought with Mr. Mudd that they did not pay enough attention to details, that is, they did not discuss their details enough. He could say for himself that he had been surprised at the amount of thought that might be expended on the simple subject of

water-gauges. Water-gauges they had been accustomed to recognise as things that existed, and to give them very little consideration. He agreed with several of the previous speakers, that it certainly was going very far out of the way in looking for simplicity if they adopted some of the devices they had placed before them that night. If they required more simplicity in the details of water-gauge fittings they certainly must not travel in that direction. He would be inclined to fit water-gauges direct on to the boilers; in that he agreed with Mr. Stoddart and some other speakers. With reference to the breakage of gauge glasses there was great diversity of opinion as to whether the glass was cooled when blown through or had been cooled before that and heated by being blown through; but it was agreed that the expansion by heat or the contraction by comparative cold was the cause of breakage. Many serious accidents had occurred since the introduction of high pressures through the breakage of gauge glasses, and the failure of the usual forms of automatic valves, and as Messrs. T. Richardson & Sons declined in all cases to fit these valves, the water-gauge which they had before them (see Plate LIV.) had been designed by Mr. D. B. Morison, with a view to minimise the existing dangers. The arrangement of cocks was just the ordinary arrangement; in fact, if the automatic cylinder was removed and the connecting links, they would simply have the ordinary water-gauge. There was no ball valve, and no hidden device. The fitting was simple and straightforward. Leaving the automatic device out of consideration in the meantime; the cocks could be opened and shut as in the ordinary case without moving the automatic arrangement at all. The quadrant on the handles allowed this to be done. The automatic device consisted of a cylinder with a piston of ordinary construction, the piston rod and connecting link connected with the two cocks by the quadrant before mentioned. The upper part of the cylinder was connected by a pipe to the upper part of the gauge glass, the under side of the cylinder connected to the column in direct communication with the boiler. In ordinary circumstances the pressure per square inch on each side of the piston was equal, and the piston being a little less in area on the bottom side, due to the piston rod passing through, the pressure of the steam tended to keep the piston at the bottom of the stroke. The arrangement of pipes was also such that any condensation was automatically drained, and the pipes and cylinder kept free. When the gauge glass was broken the pressure was at once reduced on the top side of the piston and the excess of pressure on the under side forced up the piston, which caused the two cocks to be closed at once. As Mr.

Stoddart had said, the action was practically instantaneous; there was nothing to be seen but a slight puff of steam, and under no circumstances could anyone be scalded. It might be objected that the mechanism would stick fast. He did not think this probable; but if it did, the gauge was no worse than an ordinary water-gauge, and if it did act, which he thought it would in nine cases out of ten, it was, he thought, a very valuable device. It was of very great practical importance that a reliable automatic gauge should be produced, as they all knew of accidents occurring through the breakage of the gauge glass, in which even life might have been saved by such a fitting as this. In war ships it should be very valuable, as in action the breakage of a gauge glass might cause a panic amongst the stokers at a critical time. As he had before stated, the arrangement got over the latent dangers of having valves enclosed within the cocks or fittings, which being out of sight were out of mind, and he agreed with Mr. Westgarth that sea-going engineers would not look for hidden devices, but would be quite content to leave them alone until some accident perhaps brought their existence prominently before them. In conclusion, he had to regret that business engagements had detained Mr. Morison in London and had prevented him taking part in the discussion as he had intended.

Mr. J. R. FOTHERGILL observed the discussion had so fully treated upon the principal features of the paper that he proposed to touch upon one or two points only. First of all, he wished to say there was one point in connection with gauge glasses which he thought Mr. Gray had overlooked, and that was the corroding action of boiler water under high pressure steam. He had seen many glasses which had broken from no other cause, and some of these glasses were corroded half through. Some glasses appeared to stand this action better than others, but he considered great care should be given to their examination, so that they might be taken out on the first sign of corrosion. There was no question the gauge mountings were in many cases screwed into boiler plates and standards attached to boilers out of line, but this was entirely due to the hole not being drilled true, and after the hole was once drilled and tapped it could not well be altered; but this difficulty was overcome in all first-class shops by the mountings having flanges, when there was no excuse for their not being in line. He fully agreed with the majority of the speakers that the designs of the general fittings should be of the most simple character. All complications, curved, twisted, or irregular passages through cocks or valves should rigorously be avoided, and no drain

pipe connections should be allowed to lead below the floor or out of sight. He knew of one case in which the collapsing of furnaces was due to the drain pipes leading below the engine room floor. All the cocks were very leaky, and there was a constant drain into the bilges, so much so, that the auxiliary feed was continually applied to the accumulation of scale, which brought the furnaces down. He thought the double passage cock designed by Mr. Gray was not without merit, and there was much to be said in its favour, but he suggested it yet required further developing to bring it to practical efficiency. He thought, with Mr. Mudd, that where they got an elbow like that shown by Mr. Gray there was a liability to choking and fouling, which was a weak feature. On the whole, he was in favour of the standard having the mountings fitted to it. He congratulated Mr. Hall-Brown on the very ingenious arrangement which he had shown and described, and he certainly thought there was a good future for it, for it could be applied to present fittings, which was of great advantage. Hopkinson's arrangement (Fig. 8, Plate LI.), with the automatic valve fitted at the bottom, was very reliable and satisfactory. He had several sets fitted, and although some of them had been at work nearly three years he had nothing but the most satisfactory reports; in fact, he had never received a single complaint. Much had been said relative to long connecting pipes showing false water. In two steamers under his supervision, which had large double-ended boilers, it had been necessary, due to some special fittings to the boiler fronts, to connect the bottom of the standards by long pipes to the boiler bottom, in place of the very short pipes which had immediately connected the standard to the boiler front. After the pipes were well blown through to give a true water-level in the glass, and then allowed to cool and again blown through, it was found, with the cold pipe, the glass showed a false water-level of about $2\frac{1}{2}$ inches to 3 inches. This was a fact and a matter of considerable importance, and could not be too well known.

Mr. C. J. SEAMAN said that the discussion was exceedingly interesting, but there were two points respecting which he would have liked to have heard a little more. The expansion of the gauge glass was a matter of considerable importance. Some years ago he made experiments as to the expansion of some 200 water-gauge glasses, $\frac{3}{4}$ inch diameter, with a pressure of 80 lbs., and found that in two cases the expansion reached as much as $\frac{5}{64}$ inch. There was considerable difference in the expansion shown, some glasses expanding very much more than others, and he believed it was due to this difference that occasionally it happened that a

number of glasses broke one after the other as soon as they were put in. This expansive power of the glasses rendered it very important that the clearance allowed for them in the gun-metal fittings should be ample, and emphasised the remarks as to the necessity for the fittings being in perfect line. With reference to the corrosion of the glass, which was a serious matter, this could, to a considerable extent, be overcome by using glasses with the fire-polished ends, but this interfered with their power of expanding and contracting regularly, and thus rendered them more liable to break by sudden increase or decrease of temperature. While it did not look quite so uniform, he thought there was an advantage to be gained by using two sets, having the connections to the boilers at different levels, as he had known cases where both sets had been stopped at the same time, evidently owing to the scum or oily matter floating on the water.

The discussion was then adjourned.

THE BASIS OF SHIPS' SCANTLINGS.

By J. PETREE.

[Read before the Institution, in West Hartlepool, April 25th, 1891.]

In laying before the members of this Institution the following remarks, the writer's object is that of bringing under discussion a subject the importance of which need not be emphasised, being sufficiently obvious to all concerned.

The subject has at various times received attention elsewhere, but up to the present it has not formed the special topic of discussion at a meeting of this Institution, although our President himself—so recently as the opening of this session—has pointed out very concisely the necessity of an improved system on which to regulate the scantlings of ships.

The arrangement recently made, by which representatives of this Institution will in future have a voice in the framing of Lloyd's rules for the construction of ships, not only furnishes a motive for the appearance of a short paper on the subject, but affords ground for the hope that, amongst other matters, the basis of their application to individual ships will in due time receive consideration, with a view to amendment.

Further, the inauguration of another corporation for the classification and registry of ships is in itself striking evidence of a forward tendency in these matters, and its progress will, no doubt, be regarded with all the more interest by this Institution now that the latter is in some measure associated with the older society of Lloyd's.

Lloyd's present system of numerals (originally proposed by the late Mr. B. Waymouth) has now been in operation for about twenty years, previous to which period scantlings were based upon the under-deck tonnage of a vessel. It is not surprising that the latter method should eventually prove unsatisfactory in practice; for, however excellent as a fiscal standard, the register ton is essentially unsuited to the adjustment of scantlings. No doubt a serious objection to its use was the fact that

on officially measuring a ship after she was built, the actual tonnage sometimes proved greater than originally intended, and so placed the vessel in a higher grade, which required heavier scantlings than those adopted in her construction. But, apart from that consideration, register tonnage—being solely a statement of cubical capacity—is no comparative measure of weight, except between ships of the same class, and then only within certain limits; whereas any rule which fails to recognise with reasonable accuracy the total weight of a ship must prove more or less unsuitable as a basis for scantlings and equipment.

Except as regards certain anomalous "deductions for propelling power," the register tonnage question has been satisfactorily settled for many years, and sooner or later Lloyd's rating for scantlings should also be placed on a more equitable basis than at present. Each rule must be adapted to its own special purpose, for it is equally important on the one hand to adjust a ship's dues by a rule based upon her actual capacity, which represents her earning power, and on the other to adjust her strength by a rule based upon her actual loaded weight, to which the maximum strains on the hull are directly proportionate.

The numerals now in use are so well known that they need no precise description here. For the present purpose a rough approximation is sufficient. Taking L, B, and D to represent the moulded dimensions of a vessel, and neglecting form of bilge and round-up of beam, we have:—

First numeral (affecting transverse framing) = B + 2 D.

Second numeral (affecting longitudinal framing) = L (B + 2 D).

These expressions obviously represent the girth and area respectively of the sides and bottom of a box having the same dimensions as the ship. But the first numeral, by including the depth twice and the breadth only once, places an undue restriction upon relative depth, and favours one specific proportion of depth to breadth, viz., one-half. The question as to whether such proportion is desirable or otherwise has no bearing upon the present matter. The point at issue is whether such a numeral should, however slightly, place a premium on any relative proportion to the disadvantage of others. Such was surely not the intention of those who framed the formula. The sum of breadth and depth, as adopted by another registry, being unaffected by varying proportions between these dimensions, is distinctly preferable for the purpose of this numeral, which governs all the transverse framing except beams. It would perhaps be more consistent if floors, as well as beams, were regulated solely by the mid-ship breadth, instead of, as at present, depending upon a numeral in which the vessel's *depth* is made the chief factor.

The second numeral, which governs the scantlings of longitudinal framing, shell-plating, etc., consists of the first numeral multiplied by ship's length. In vessels of identical proportions this numeral would vary as the square of a principal dimension, the light weight of ship as a higher power, the load displacement (at proportionate draught) as the cube, and the longitudinal bending moment as the fourth power of the dimension. Hence, in passing from one plating numeral to the next, both the weights and strains involved (especially the latter) are much in excess of the ratio between those numerals. But confining ourselves to one plating numeral, it is evident that on the same dimensions and draught the displacement may be large or small, according to the form of the vessel, yet this possible variation has no corresponding effect upon the numeral and scantling. It is true that quite recently a special clause has been inserted, offering an indefinite concession to ships of exceptionally fine form, or for certain lighter classes of service. But, quite apart from special cases, it is reasonable to expect that varying displacement should be duly recognised as the most important factor in such a numeral, since between the respective extremes there may be very considerable difference. For instance, while the dimensions, plating numeral, and scantlings of a ship remain unchanged, the displacement coefficient may be any value between, say, ·4 and ·8; and assuming the maximum bending moment to vary as the displacement—length being constant—the factor of safety to resist that stress would in the latter case be only one-half of the former, therefore the same scantlings cannot fairly apply to both ships.

With regard to the equipment of anchors and chains, the load displacement alone should be the basis of comparison, whatever may be the ship's dimensions or proportions. To estimate the equipment without considering the actual weight to be held is somewhat (though not quite) analogous to estimating engine power regardless of the weight to be driven.

That there are difficulties in the application of a displacement basis cannot be denied, but they are not insuperable. Greater difficulties have always surrounded the load-line question, yet that problem is now nearer a permanent solution than ever before.

The displacement is not only the principal element but also the most elastic element in a ship's design, and for the latter reason alone ought not to be neglected in rating the scantlings. On the contrary, it is quite as legitimate—and much more important—to limit the displacement permissible with certain scantlings, as such a comparatively irrelevant factor as the midship girth.

Though the displacement basis for scantlings does not necessarily involve an arbitrary load-line, the convenient application of the one might—and probably would—include the other, in which event the maximum load draught would become a condition of classification for every ship, as it has long been for awning-decked ships. And as in a vessel of the latter type the approximate displacement could, if required, be submitted simultaneously with the dimensions, etc., it is reasonable to infer that a similar method might with advantage be applied to other classes. But when once the real element of displacement is introduced, the artificial numerals may well be dispensed with.

It is not the writer's present purpose to submit any amended formulæ, but to suggest, in conclusion, that some regulation based upon the actual load displacement would be more consistent in its general effect upon ships of various designs than the numerals now in use, and would more fairly represent the maximum stress contemplated by the registry in assigning to the ship a certain class; the principal factors to consider being dimensions, proportions, displacement, type of vessel, and nature of service in which to be employed.

DISCUSSION.

Mr. T. PHILLIPS said the author of the paper was to be congratulated on his boldness in venturing on a subject which was thought to have been practically exhausted, and it was certainly interesting to find the results summed up in the remark that "it is not the writer's present purpose to submit any amended formula," which he took to mean that he would leave, as had others, the ideas of scantlings on a displacement basis for further discussion and investigation. The subject of the method of determining the scantlings for ships was well worthy of enquiry at a meeting of this kind, and if any new thoughts on this matter could be set forth, he was perfectly confident there would be no hesitancy on the part of the scientific staff of Lloyd's Register to take the useful points into consideration. It might be interesting to this meeting to learn that the subject of the scantlings of vessels had occupied the attention of the Institution of Naval Architects on many occasions, and although Lloyd's rules had been criticised adversely, yet, beyond mere expressions of opinion, no one had ventured to formulate rules for scantlings embodying his particular ideas and fancies. The scientific staff of Lloyd's Register had, however, given serious thought to all opinions as regards the best methods of fixing scantlings, and, further-

more, had formulated more than one plan, and submitted the same to builders where displacement was a factor in determining scantlings, and, although approved by some, the builders throughout the country all differed from each other as to the proper mode of effecting this, while the consensus of opinion was that the displacement basis was inferior to the existing system of Lloyd's Register. In the paper the writer pointed out, that, the first number for scantlings by including the breadth once and the depth twice places an undue restriction on relative depth. In reply to this, it might be stated that the framing number obtained in the manner described in Lloyd's rules very closely represents the proportionate area of the mid-ship section, where the breadth approaches that of 1 to 2, and it was only in exceptional cases where this proportion was largely departed from, that any appreciable percentage of difference would be found to exist. It was also suggested that the floor should be regulated by the breadth alone. If this were done then the floor plate would be required to be the same in all vessels of the same depth, irrespective of the type of the vessel, although the dead-weight carried would vary considerably with the different types. With regard to the suggestion that the load-line displacement should regulate the equipment, if this were the case, the amount of surface or bulk out of water exposed to the force of the wind would be neglected. It was noted that the writer was cognisant of difficulties that arose in the case of vessels when under-deck tonnage formed the basis for the scantlings. He would therefore fully appreciate and no doubt be in a position to reply to the following remarks :—By the existing method, as soon as the sketches of a vessel had received the approval of Lloyd's Committee, which could be done before aught of the displacement was known, the materials to be used in the construction could be ordered from the manufacturers forthwith. And there need be no apprehension at any time that the vessel was being constructed with improper scantlings. On the other hand, until the vessel was practically designed and fully laid off, nothing was known with any degree of accuracy of the displacement, and it would be quite an innovation in shipbuilding matters, and a decided disadvantage, if the ordering of materials was compulsorily deferred until such a late period. He was induced to refer to a remark [illegible] Mr. William John at the meetings of the Institution [illegible]77, viz., that, in dealing with the question of [illegible]rties to be considered, if not more, [illegible] the classification societies, an[illegible] country knew the displacement[illegible]

ment? They cared for the carrying capacity of their ships, but they did not care for the displacement; and frequently, in arranging with the builders, it was the case that they stipulated for certain dimensions, they stipulated for certain carrying capacity, and if also they were to stipulate for displacement they would tie their own hands, and have no hold whatever over the builders to ensure having their primary object, viz., carrying capacity, fulfilled. He would conclude by remarking that the scantlings, as determined by Lloyd's rules, had given universal satisfaction, and, as they had stood the test of over twenty years' experience, it was to him a matter of considerable satisfaction that nothing as yet of a tangible character had been suggested to show that Lloyd's rules had been built up on an improper basis; and he ventured the opinion that, on account of practical and almost insurmountable difficulties, shipbuilding rules were not likely to be improved or made workable by the introduction of a new system for scantlings built up on the basis of displacement. He had to express his thanks for the opportunity given him to make these remarks.

Mr. HUGH MACOLL, who thought it would be better to leave the discussion there to local members, said the subject of the paper was of a very useful kind if properly carried out, and the suggestion that displacement should form part of the classification rules was, he thought, a very good one. Besides the three parties indicated as represented, there was another party outside of these that might be called the public, represented by the underwriters, who were also worthy of being considered, and who, on Lloyd's Register, was very largely considered, more than even the shipbuilders or shipowners. However, as to the question of displacement in a new vessel, he did not think there was much difficulty in getting it within a few tons. They knew what it was to be, and it was an easy matter for a vessel to come within a few tons, just as it was to get the present scantlings. He did not say that the displacement only, though the displacement should form one of the principal factors in the construction of a vessel. Vessels of high speed were necessarily of fine lines, and certain high speed vessels could not be constructed under Lloyd's rules, simply because they would be over-weighted with their own material, and be useless for their intended trade. The great bulk of paddle steamers, for instance, had no place in Lloyd's Register. They did their work perfectly well, but if weighted with an addition to the hull they could not do the speed in shallow water. The bulk of the ship was touched upon by Mr. Phillips as the necessary thing

to be considered in regulating the scantlings. If the vessel was at anchor certainly the bulk to be above the water must be considered, and the displacement there was not of such a vital character; but tonnage was, on account of new practices, getting to be a very unreliable factor. There had been a great many alterations lately, and they did not know how many more they might get. It was desirable that some finality should be obtained. They had altered the tonnage by Board of Trade new rules for under-deck by something like 100 tons in some vessels, and vessels having ordinary water ballast tanks were still liable to be re-measured. A vessel in the course of a few years might have three or four different under-deck tonnages, whilst the displacement would remain the same. One thing in taking a displacement basis was very desirable, that a very full ship, the "beast of burden," should have a larger addition to her mid-ship scantling, and this would tend somewhat to counteract that desire of some shipowners to carry the greatest possible dead-weight on the least quantity of material. The very full ship in stormy weather tends to strain a great deal more than a fine vessel; there is more weight and stress thrown upon the mid-ship portion of the girder in the centre, yet the quantity of material is just the same as if she carried a great deal less and was less punished by the additional weight carried in the ends. Therefore he thought in this direction there was room for improvement; and if shipbuilders and shipowners were in such a dreadful hurry as not to be able to wait till the displacement, which could be got approximately in a few minutes and accurately in a few hours, was ascertained, they should stand the consequences. It seemed to him rather curious to hear objections to displacement when all the freeboard rules and tables were avowedly based on the load displacement as the principal factor, and in the case of vessels with extra deep floors, double bottoms, and such like, allowances have to be made to obtain the normal tonnage coefficient, whereas the actual displacement coefficient would give exactly what was wanted at once.

Mr. A. McGLASHAN said he thought the subject of the paper more fascinating when first stated than it was after investigation. For years it seemed to him that the present system of fixing scantlings was radically wrong; but experience, and investigation, and efforts to improve upon the present methods had convinced him that they might go further into error by adopting the suggestions contained in the paper. The displacement basis for fixing scantlings was not advocated now for the first nor the twentieth time. As is pointed out in the paper

Mr. W. T. COURTIER-DUTTON was not aware that his colleague (Mr. Phillips) had intended speaking on this subject, and he felt that the wind had been to some extent taken out of his sails. He would like, however, to offer one or two remarks on points not touched upon by his friend, Mr. Phillips. He thought they ought not to lose sight of the practical difficulties against adopting displacement as a measure for determining what a vessel's scantlings should be, and he might be pardoned for saying, as a Lloyd's surveyor, that these difficulties were presented to them in a way which Mr. Petree was unfamiliar with. When a shipbuilder submitted plans for approval, through the local surveyor, the committee expected the surveyor to satisfy himself as to the correctness of the dimensions upon which the scantling numerals were based, and this he could easily do from the plans with the help of a pair of dividers and a scale, or more correctly still from the scrieve boards before the work was commenced; while if the element of displacement were introduced the committee would hold the surveyor no less responsible for its accuracy, and this would lead to all sorts of vexatious delays to the builder, and of which he would be the very first to complain; for the surveyor would either have to go into the builder's drawing office and check the displacement calculation from the lines, or he would have to ask the builder to submit a body plan of the vessel, which he (Mr. Courtier-Dutton) thought no builder would care to do. Mr. Phillips had referred to the paper by the late Mr. Denny on this subject, and to the remarks made by the late Mr. John in the discussion which followed, and he (Mr. Courtier-Dutton) would like to draw attention to a point not touched upon by Mr. Phillips. In the earlier part of Mr. John's remarks he stated:—"I do not think it (the displacement basis) will work, for the reason that there is nothing definite about it. Either Lloyd's must fix a load-line and get a definite displacement, and that must be a hard and fast line, or else if it is not the correct load-line for the ship then it is a fictitious load-line, and therefore a fictitious basis for scantlings." He (Mr. Courtier-Dutton) thought that these remarks had even more force now than when Mr. John uttered them, for we had now to administer a load-line, and this could not be determined with accuracy, nor consequently could the corresponding displacement be finally fixed until we had the Board of Trade under-deck tonnage, which was not obtainable until near the completion of the vessel. To carry this a little further, it was now optional with an owner in the case of a particular type of vessel, almost at any time after she was built, to materially increase her displacement by stiffening up the bridge bulkhead and other minor additions,

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

SEVENTH SESSION, 1890-91.

PROCEEDINGS.

CLOSING BUSINESS MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON MONDAY EVENING, MAY 11TH, 1891.

WIGHAM RICHARDSON, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting, held in West Hartlepool, on April 25th, which were approved by the members present, and signed by the President.

The ballot for new members having been taken, the President appointed Messrs. Wm. Boyd and H. Macoll to examine the voting papers, and the following gentlemen were declared elected:—

MEMBERS.

Elliot, Henry, Engineer Draughtsman, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain.

Ford, David, Engineer Draughtsman, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain.

Hawdon, Joseph Y., Engineer to Messrs. C. S. Swan & Hunter, Wallsend; 16, North View, Heaton, Newcastle-on-Tyne.

Macmillan, Walter, Engineer Draughtsman, c/o Sociedad Anonima, Astilleros del Nervion, Bilbao, Spain.

Topham, Henry George, Marine Engineer, 17, Grafton Road, Whitley, Northumberland.

THE PRESIDENT remarked that he was glad to see that the Institution was always increasing in numbers.

The discussions on the following papers were closed:—

On "The Unsinkability of Cargo-Carrying Vessels" (second paper), by Mr. W. Hök.

On "Water-Gauge Fittings for Steam Boilers," by Mr. Harry Gray.

On "The Basis of Ships' Scantlings," by Mr. J. Petree.

The Closing Business of the session then followed.

ADJOURNED DISCUSSION ON MR. W. HÖK'S SECOND PAPER ON "THE UNSINKABILITY OF CARGO-CARRYING VESSELS."

The PRESIDENT said they had no papers to read that evening. He believed some members considered that they had had too many papers during the session. They had now three papers to discuss. There was first Mr. Hök's paper on "The Unsinkability of Cargo-Carrying Vessels," discussed at some length at the last meeting. He did not know if there was any gentleman had anything further to say on the question, if not, he would call upon Mr. Hök to reply.

MR. HÖK'S REPLY.

Mr. W. HÖK, in replying, said, in the discussions on this paper at Sunderland and Hartlepool, there was hardly any controversial matter introduced, consequently he hoped to be able to make a short reply. There was just one remark by Mr. Doxford he would like to refer to in order to obviate any misunderstanding. Mr. Doxford's words were these:—"The proportion of ships lost by collision was so comparatively small to the total number of vessels built, that he did not think any shipbuilder in existence would object to fit additional bulkheads lest the number of losses should be reduced. He hoped they all took a much higher view of the great responsibilities resting upon them." He (Mr. Hök) must point out in justice to himself, that he did not even breathe the thought that the shipbuilder would object to fit a sufficient number of bulkheads in ships to make them practically unsinkable; what he said was merely this, that the shipbuilder and the insurance companies would suffer by so doing. Strictly speaking, the commercial aspect of the case was not a shipbuilder's matter at all, and why he included the shipbuilder was merely because he was so closely connected with the technical part of the question, and because this paper was read before a shipbuilders' Institution.

Mr. Macoll did not agree with him that it was possible to construct unsinkable ships. There was no need for arguing the question, as it was only a matter of how they defined an unsinkable ship. If Mr. Macoll, by an unsinkable ship, meant a ship that could not be destroyed, he was, of course, right, whereas if his (Mr. Hök's) definition of an unsinkable ship was accepted, Mr. Macoll was undoubtedly wrong.

Mr. McGlashan entertained grave fears that the further subdivision of ships would increase the tonnage, and in this way increase expenses. From what he knew of the types of ships, such as the raised quarter-deck vessels, the switchback vessels, and the spar-deck vessels, that had now the preference, it seemed to him that tonnage had to some extent stepped into the background. Besides, it would be noticed that nothing that he had proposed in the paper would increase the tonnage of any ship or type one iota; in fact, in no instance was such a course needed. Then, again, they could not agree on the purpose for which bulkheads were fitted. What he maintained was this, that water-tight bulkheads were compulsory in ships for the sake of providing safety, and he saw no reason, so far, to alter his opinion. It was evident that water-tight bulkheads provided transverse strength (they could not help it), but they were not put there for this purpose. If so, they were the clumsiest and most expensive contrivances ever invented for a certain purpose, and did credit to no one; and the fact mentioned in the paper that the vessels that were more liable to transverse alteration of form than any other vessels, *i.e.*, sailing vessels, did not require bulkheads proved clearly that the bulkheads in steamers were put there for other purposes than strength. It was easy to prove that the compulsory bulkheads were not fitted for the purpose of forming partitions. All shipbuilding practice went against that contention. Who ever put in $\frac{7}{16}$ inch plating, and stiffeners of the same strength as frames when it was the question of putting in a partition bulkhead? And then, again, Mr. McGlashan said that "it was doubtful if water-tight subdivision would have become common to the extent it had in cargo ships if the working of the ships had not required them." He never thought they required bulkheads in order to facilitate the working of ships; on the contrary, he thought that the real reason why bulkheads were objected to, was their property of increasing the difficulty of stowing and working the ships. And what about sailing vessels without any bulkheads at all? They would be difficult to work if Mr. McGlashan's contention was right; so therefore he was bound to maintain his opinion that water-tight bulkheads were fitted for the purpose of providing safety, and not for strength, or for the purpose of serving as partitions; of course, once fitted, they could not help serving the purposes of both, and that fact was also taken advantage of by the builders as was well-known. Mr. McGlashan had also pointed out that in some cases the holds would be so small, and the bulkheads come so close together, that there would be more danger of a bulkhead being injured than the writer admitted. This was perfectly true, and he was aware of

it, but it must be understood that the subdivision found in Tables XIV. and XV. (pages 349-351) was the minimum subdivision *required* for ships at their present load draughts. What he *proposed* in order to improve ships, that it was practicable to improve, was found on page 346. It was impossible to make small vessels as they now were unsinkable. To them they required to apply a radical cure, which would be superficially mentioned later on.

Mr. Yeoman gave them some very interesting statistics; but, while they must be greatly obliged to him for the interesting statistics he repeatedly took the trouble of laying before them, they must not forget that statistics were the most powerful weapons to prove or disprove anything they liked. Of course he did not hereby question for a moment the accuracy of his figures. They seemed to prove that the loss of life at sea was so small that the present state of things with regard to safety was good enough. They also showed that sailing crafts accounted proportionally for a greater number of lives than steamers, and therefore proved at all events that sailing vessels should, in order to be placed on equal footing with other vessels, be made safer and more seaworthy. To Mr. Yeoman's statistics he begged to add the Board of Trade returns of losses for the year 1888-89, in the British mercantile marine. Total losses at sea amounted to 753 vessels, or 234,000 tons; missing vessels, 67; serious casualties not resulting in total loss, 2,387; lives lost, 2,233, out of which 1,444 lives perished in the missing vessels. Mr. Yeoman also showed by the number of lives lost in the home trade that the vessels belonging to the mercantile marine were well navigated. That might be as far as life went, but what about property? According to Mr. Yeoman about 49,000 vessels cleared from the United Kingdom in a year, and according to the Board of Trade returns for 1888-89 he (Mr. Hök) found that during that year about 4,300 casualties occurred on or near the coast of the United Kingdom, which was about 1 for every 10 ships, and also that during the same year over one-third of all vessels registered in the United Kingdom met with some kind of disaster. So if Mr. Yeoman's figures showed that the loss of life was comparatively small, his figures showed that the loss of property was great. Then, Mr. Yeoman sounded the warning note that the shipping should not be interfered with on account of severe foreign competition due to alleged overloading of foreign ships, etc. As the subject was without the province of his paper he should abstain from referring to it. He could not, however, refrain from saying that if Mr. Samuel Plimsoll had been there he would have told them a different tale. And also that the British shipowners had succeeded in getting rid of their

old-fashioned sailing vessels, which Mr. Yeoman's figures clearly showed, was, he thought, something to be thankful for. The parallel drawn by Mr. Yeoman between the Tay Bridge disaster and the foundering of the "Utopia" served to remind them in what different light the railway engineer and the shipowner looked upon such disasters. Whereas the railway engineer would replace the old structure by a new one that would, to the best of his knowledge meet all emergencies, the average shipowner would replace his ship by another one, either old or new, of similar construction, and, then, in the old way trust to chance once more.

Mr. FOTHERGILL—I object to that.

Mr. Macoll and Mr. McGlashan both believed that new unsinkable ships would be dreadfully handicapped in competition with the old ones, and asked what they could do with the old ships? Should they be altered and added to, just as recently had been the case with the compulsory fitting of life-saving appliances, and assigning of load-lines? It was his belief that the only fair course to adopt was to leave the old vessels alone and offer the new ones such advantages in the way of special marks, reduced insurance, etc., that it would be profitable to build them. In order to make the matter a complete success, first recognise the principle of unsinkability, and connect the number of bulkheads with freeboard. It was only fair towards human life and property that this should be done. Then base tonnage and scantlings on the displacement. The freeboards could then be increased for some types, especially for small vessels, that it would be possible, without the slightest difficulty, to so subdivide them as to make them practically unsinkable. Such ships would fear no competition with old ones, when now scantlings and insurance premiums were reduced, tonnage rated on displacement, and special marks provided that would indicate safety. It would be impracticable, and also unfair to interfere with the old vessels, as some of them, if they were sufficiently subdivided with their present load-line, would never be able to enter into competition again. No, build new vessels according to new rules, and let the old ones take their chance in the same way as wood ships had to do when iron was introduced; sailing vessels on the introduction of steam; iron vessels on the introduction of steel; and ships with compound engines on the introduction of triple expansion. It must be admitted that if ships were made unsinkable the loss of life and property would decrease. It was, of course, impossible to divine to what extent, but it seemed plain that putting

life aside, the amount of property now annually lost would then be greatly reduced. If vessels collided, total loss would be prevented; if they ran ashore, it would be infinitely easier to salve them: in fact, many a vessel that could not now be salved from want of sufficient time would then be brought to port successfully; and such common occurrences as ships foundering in deep water after striking a rock or something unknown would then undoubtedly be rare. So it seemed to him that the saving from total loss, and the greater facility with which salvage operations could be accomplished, would substantially reduce the losses of the nation, represented by the insurance premiums paid, due to carrying merchandise in a defective way. It was to be hoped that a policy more conformable to the economic laws that so successfully guided this nation in other matters, would to its fullest extent be adopted by the shipping community. Finally, he begged to thank them most heartily for the kind reception of his paper and the instructive discussion that ensued.

The PRESIDENT observed that the paper had excited a great deal of interest and a great deal of discussion and a great deal of dissent; but he was sure they would join with him in passing, by acclamation, a vote of thanks to Mr. Hök for the trouble he had taken in placing it before them.

The vote was accorded by acclamation.

ADJOURNED DISCUSSION ON MR. HARRY GRAY'S PAPER ON "WATER-GAUGE FITTINGS FOR STEAM BOILERS."

The PRESIDENT said they had a paper read at the last meeting in Hartlepool by Mr. Harry Gray on "Water-Gauge Fittings." It was a paper very beautifully illustrated, such as they seldom had. They also had a model shown, an invention of Mr. D. B. Morison, the principal engineer of the firm of Messrs. Thomas Richardson & Sons. Among those present at Hartlepool there was very great diversity of opinion. They had Mr. Mudd, of the Central Engine Works, Mr. Stoddart, of Lloyds, and Mr. Hall-Brown, from Messrs. Thomas Richardson & Sons, and Mr. Westgarth, and these very great authorities all seemed of different opinions. He had to ask if there was any gentleman who would like to say anything more on the subject? There being no response he would call upon Mr. Gray to reply.

MR. HARRY GRAY'S REPLY.

Mr. HARRY GRAY said, in reply to the various points which had been raised during the discussion, he would first of all like to remove any feeling that exaggeration had been used to draw attention to the dangers attached to certain cases, as mentioned by Mr. Mudd. To such an Institution as this the simple facts of the case should suffice, and he trusted that Mr. Mudd, as well as those present, would exonerate him from any such intention. His meaning was fully defined by Mr. Mudd himself when he said that "very likely the boiler would be burnt and damaged." Now, he understood that such damage resulting in the disabling of the boiler, either by the collapse of any part, just the same as by the bursting of any part, was within the meaning of the Act dealing with boiler explosions, and treated by the Board of Trade as an "explosion," hence his use of the term on the point in question. With reference to the question of hollow standards and the use of external pipes, upon which several members had expressed their opinion, and also upon the question of simplicity, he would say, as in the paper, "in every detail contributing to the *efficient* working of the whole," they must have efficiency, and it was well to get it as simply as possible, but have it they must, and by doing away with cocks or valves on the boiler ends of external pipes, as proposed by Mr. Westgarth, contributed to neither efficiency nor simplicity, the passage through the standard preventing the independent testing of the steam and water connection pipes, but where

shut-off cocks were placed on the boiler a means was provided of separately testing each connection; still the fact remained that this was not done as often as it should be from the cases as stated in the paper, and was even a source of danger, as shown in the case mentioned by Mr. Stoddart, where the cock on the steam connection was not re-opened. Hence his argument in favour of efficiency combined with simplicity, as shown in Figs. 1 and 2, Plate XLVIII., of the paper. Prevention was better than cure. By these means a man was prevented from making any partial test, and since the whole operation was performed by the one cock or valve (Figs. 4 and 5, Plate XLIX.) he could scarcely forget to re-open it, or he would have no water showing in his glass; also this arrangement enabled the test to be made without requiring the engineer to place himself dangerously near the glass, and should it chance to break he could instantly at any time shut off the water. In dealing with these questions where the practical working was being considered, the men whose duty it was to attend to and examine the water-level must be considered also, and although as a class they were well able to hold their own, and from whose ranks had risen many of those who were the acknowledged authorities upon all matters of engineering, still they had to be prepared for some careless ones, as well as to help those who had at times their abilities tried to the utmost in cases of emergency or heavy weather at sea, and it was in such meetings as this where the work of perfecting must be done through the interchange of opinion and experience. Several members had taken exception to the form of standard as shown in Fig. 1, Plate XLVIII., on account of the two bends, but in ordinary hollow standards these bends in the line of communication at present existed, consequently the objection must be to the upper bend on account of a tendency to choke, but upon consideration it would be seen that by the arrangements provided for testing (Figs. 4 and 5, Plate XLIX) all the passages must be blown through, which would keep removing any deposit that attempted to lie there, which action also prevented any deposit taking place in the horizontal passages of the upper and lower mountings, and as only one way of communication was afforded instead of two, in the case of the hollow standard, such action was ensured. With regard to the size of the passages, it would seem to be a matter of "first cost;" everyone must agree with Mr. Mudd's remarks on this point. When water-gauges were fitted direct to the boiler, Mr. Seaman's suggestion of fitting two sets at *different* levels was worthy of note, on account, as he stated, of the reduced liability of their both becoming choked at the same time. It was this liability of their becom-

ing choked, on account of the openings to the interior of the boiler being exposed to the wash of the water-level over them, and the consequent liability of the deposit of any scum that might be floating on the surface in such passages, combined with the un-get-at-ability of internal pipes, that led him to favour the external pipe arrangements, with their advantages of testing, examination, and repair, even whilst the boiler was under steam, etc., as against any disadvantages they might possess. The question as to the cause of the breakage of the gauge glass, although the most common source of derangement of the gauge, had not met with the consideration that he ventured to think it was entitled to. Mr. Mudd drew attention to an apparent contradiction in the cases as stated in the paper, in both of which the breakage was attributed to the same force, under the two extreme conditions under which the glass might be placed, either through the reduction of the temperature when testing the water-level, or by the reduction of the temperature of the lower portion of the glass, etc., by the cooling of the water in the lower connections through not testing. In the first case the breakage was attributed to sudden contraction upon lowering the pressure and temperature upon blowing through, combined with the sudden expansion upon the temperature being raised again when the pressure was brought upon it. In the second case the glass was under unequal expansion, the upper portion being that due to the temperature of the steam, and the lower part to that due to the temperature of the water, which, by remaining unmoved in the pipe, etc., through non-testing of the glass, etc., had cooled down. This, as stated, might account for the breakage of the glass, at such times as when it had not had the double strain which existed upon the glass being blown through, as in the first case, and which action occurred as much in the second case as in the first, upon the glass being blown through, except that the temperature of the lower portion of the glass was under contraction already. So that when the glass broke just after it had been tested, it was due to the sudden expansion whether the glass was previously under conditions similar either to those of the first or the second case, whilst in the second case they had a reason for the glass breaking at such times as it had not been recently tested. The data given by Mr. Seaman with reference to certain experiments made in order to ascertain the amount of expansion of gauge glasses was most valuable evidence in support of this theory, showing at 80 lbs. pressure or 312 degs. Fah. an expansion in two cases of as much as $\frac{5}{64}$ inch on the diameter of a $\frac{5}{4}$ inch glass, proving that a perceptible expansion did take place. When such was considered with reference to the length of the glass it became con-

siderable, such action taking place whenever the glass was blown through, and must tend to reduce the strength of the glass to resist such a strain. This also tended to show the necessity for having the fittings perfectly in line, as mentioned in the paper, to ensure the clearance provided being available, and not as in Figs. 12 and 13, Plate LIII. The corrosion of the glass under high pressure steam was a matter of growing importance, and he had to thank Mr. Fothergill for drawing attention to this omission in the paper; but, judging from Mr. Seaman's experience, they must be content with the ordinary glass, renewing the same from time to time when required, as whilst glasses with fire-polished ends seemed to overcome the deterioration, they appeared to be less able to withstand the constant strain of contraction and expansion of the working conditions. The objection to the springs introduced to reduce the extent of the variation of temperature upon the glass when testing the water-level, etc. (Fig. 5, Plate XLIX.; Fig. 10, Plate LII.), upon the ground of complication, should not exist when it was remembered that *not one* of such springs were in the *passages* of the mountings, and were so fitted that in the event of their not effecting the purpose they were intended for, either by breakage or other cause, they could not possibly effect the efficient testing of the gauge, whereas by their action protection was afforded to the glass from inside influences during testing, no fitting on the boiler being more simple. The statement in the paper referring to the lowering of the water-level in the glass by the cooling of the water in the external pipes had raised some comment. The results given in the paper were calculated from data as supplied by Prof. Rankine and also Mr. C. D. Clark in their works, and in support of which he might state that it had been found in some cases where priming had baffled all attempts to counteract it, that the fact of the water-level in the boiler being higher than that shown in the gauge glass, from the coldness of the water in the external pipe, had been found to be the chief cause of the priming, and it would be found in all cases that the accuracy of the water-level would depend upon the water in the gauge glass connections being of the same temperature as that in the boiler, and the greater the difference of such the greater would be the variation of the water-level in the glass from that in the boiler in proportion to their length. He was pleased to see the idea of Messrs. Lebrun and Comerais, of Paris, for the automatic closing of the shut-off cocks of the water-gauge by the action of a piston in a small cylinder, attached to the handles, as described by Mr. Hall-Brown. He understood from Mr. Morison that he had acquired the patent rights for this gauge, and to which he had added an improved

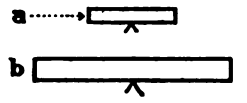
method of connecting the piston rod and link to the cocks by means of the quadrant handle, thereby enabling the independent action of each cock without interfering with the action of the automatic closing. The external nature of this arrangement was advantageous, but whether its action would be liable to derangement by choking of either of the steam connections, causing it to fail in acting, or by reduction of pressure above the piston by condensation upon the steam pipe being stopped up, causing it to close, was a point to be tested under working conditions upon a voyage, and it should not require cleaning out every fortnight, as he was told a few days ago one of Messrs. Dewrance's did, on account of a scale accumulating on the ball valve. As a possible protection in the event of the glass breaking it must find a welcome from all sea-going engineers. He thanked them for their kind attention and assistance in the discussion.

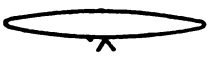
The PRESIDENT said he hoped they would allow him to move a vote of thanks to Mr. Gray, and that they would be kind enough to pass it by acclamation.

The motion was so carried.

ADJOURNED DISCUSSION ON MR. J. PETREE'S PAPER ON "THE BASIS OF SHIPS' SCANTLINGS."

The PRESIDENT said the other paper they had had read was Mr. Petree's paper on "The Basis of Ships' Scantlings," and before he called upon any discussion he should like to say that some members of their Institution, who were not engineers or shipbuilders, had spoken to him of one phrase in the paper, and asked that the author would explain it. As the author was not present that night they might perhaps take from him a word on the subject, although most of them were perfectly familiar with the point, and his going into it now might appear very elementary. The phrase was that—"The longitudinal bending moment varied as the fourth power of the dimension." Since he was supposed to be speaking to non-technical men he had prepared here two models (see sketch). Of course Mr. Petree was speaking of the ship as a girder, and they must suppose that *a* was the ship suspended on a rock in the centre. There was a certain strain, a certain tendency to break the back of that ship. If now he took another girder, *b*, twice the size, and also suspended it in the centre, common-sense said the one was no stronger than the other. This one, *a*, held all its weight without giving way, and so did that one, *b*; and yet to the non-technical mind it seemed extraordinary to say that the bending moment of this ship, *b*, should be sixteen times the bending moment of that ship, *a*. He took the author to mean that the dimensions being each doubled, the weight was increased as the cube of 2, or eight times, and the length of the leverage being also doubled, it followed that the bending moment is the multiple of the cube and of the first power—in other words, the fourth power. The author, doubtless, put it in this form so as to keep out all the questions as to the strength of the vessel to resist the strain. The strength of the girder increased as the distance of the plating from the neutral axis, so that the rules of Lloyd's Society, and of the International Society of Veritas are not so far out as might be imagined from the statement of the writer. In that connection he might further go on to say, that if a vessel was tapered at the ends as this model was (see sketch), they would very much decrease the bending moment, the centre of weight being moved nearer to the





fulcrum. Furthermore, the girder being tapered like a ship's yard, there would be an additional strength, due to the more equable distribution of the resistance to the strains. He begged they would understand that he had made these observations only at special request, but he would claim their indulgence at the conclusion of the discussion to make a few remarks upon the paper itself, and on the discussion.

Mr. HÖK was sure they must all be very much obliged to Mr. Petree for having introduced this very important subject to the Institution. He was sure that every one of them would be very glad if this question of the true basis for scantlings were solved, and he only regretted that he could not contribute anything of value towards its solution. The reason why he rose to take part in the discussion was merely to correct what he thought a few inaccuracies in the paper. On page 394 Mr. Petree said that the actual capacity, or the tonnage, represented the earning power of the ship. If they only considered two ships of the same dead-weight, one a three-deck ship with small tonnage and one an awning-deck ship with large tonnage, it was clear enough that no one was justified in saying that the actual capacity represented the earning power. On page 394 Mr. Petree said:—"The first numeral, by including the depth twice and the breadth only once, places an undue restriction upon relative depth, and favours one specific proportion of depth to breadth—viz one-half." This was correct; but he referred to the paragraph, because he had got out a direct mathematical proof that it was so, and, if interesting to the Institution, he would append it to his remarks:—

Proof that Lloyd's numerals favour one specific proportion of depth to breadth—viz., one-half.

Call the proportion of depth to breadth $= x = \frac{D}{B}$, if B = breadth and D = depth.

The problem is to find what value of x will make the numeral B + 2D a minimum for a given area of mid-ship section = B × D, equal to 1 for the sake of simplicity.

Numeral = B + 2D = $\frac{1}{\sqrt{x}} + 2\sqrt{x}$ · · · (1), if expressed by the ratio of depth to breadth, x.

To obtain the minimum value of the numeral, find the 1st and 2nd derivative of (1), being—

$$f'(x) = \frac{1}{\sqrt{x}} - \frac{1}{2x\sqrt{x}} \cdot \cdot \cdot \cdot (2)$$

$$f''(x) = \frac{1}{2x\sqrt{x}}\left[\frac{3}{2x} - 1\right] \cdot \cdot \cdot (3)$$

Put $f'(x) = 0$; and $x = \frac{1}{2}$.

For this value of x, $f''(x) > 0$, from which follows that the numeral is a minimum.

Therefore the ratio of depth to breadth that Lloyd's numerals favour is $\frac{1}{2}$.

The value of the minimum numeral is $2\sqrt{2}$ for unit area, and $B = \sqrt{2}$ and $D = \frac{1}{2}\sqrt{2}$.

Then Mr. Petree said further on:—"It would, perhaps, be more consistent if floors, as well as beams, were regulated solely by the mid-ship breadth, instead of, as at present, depending upon a numeral in which the vessel's *depth* is made the chief factor." Well, he thought that Mr. Petree was wrong here. If they considered two ships of equal breadth, it was evident that a depth of 30 feet, for instance, would require a far heavier floor than a depth of say 10 feet.

The PRESIDENT—Are you presuming upon the same displacement?

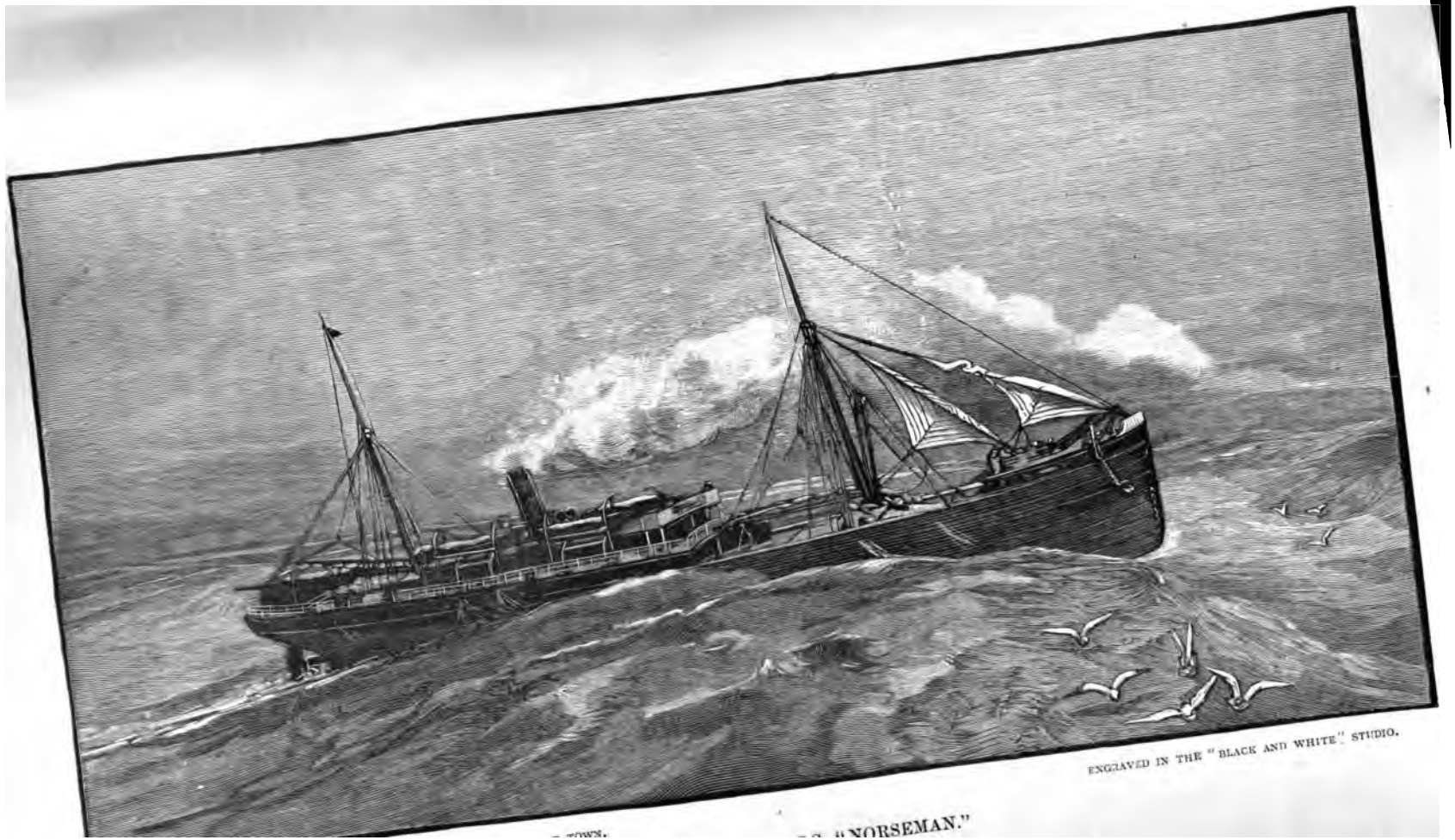
Mr. HÖK—Certainly not. Or if they imagined two ships in a dry dock resting on their keels on the blocks, it would then be more easily understood that the stresses the floors were subjected to in a ship of considerable depth must be far greater than in a ship of very small depth. But he believed that single-deck ships could be constructed with lighter floors than ships with two or three decks of same dimensions; because the forces acting on the floors in these two different types were, although of same total amount, yet differently applied. In the latter case part of the cargo was carried through the frames by the ends, and through the pillars by the centre of the floors, and thus partly concentrated at three points; but in a single-deck ship all the cargo was evenly distributed over the floors. This dissimilar distribution of the cargo caused a reduction of stress in the floors of the single-deck ship, and they could therefore, perhaps, be made somewhat lighter. Then on page 395 Mr. Petree said:—"For instance, while the dimensions, plating numeral, and scantlings of a ship remain unchanged, the displacement coefficient may be any value between say ·4 and ·8; and assuming the maximum bending moment to vary as the displacement—length being constant—the factor of safety to resist that stress would in the latter case be only one-half of the former, therefore the same scantlings cannot fairly apply to both ships." This would, perhaps, be correct, if it was right to assume that the maximum bending moment varied as the displacement, which it certainly did not. This fact would be easily understood, if they considered what caused the bending moment in ships. It was

due to the distribution of buoyancy in relation to weight. If a cargo vessel was assumed to be at rest on a wave crest, it was due to the excess of buoyancy over weight in the centre, and the excess of weight over buoyancy at the ends. Supposing, in a loaded ship, there was no excess of buoyancy over weight, or weight over buoyancy, at any section, there would be no longitudinal bending moment in that ship. If they took a fine ship with a coefficient ·4, and gradually filled her out till her fulness became ·8, the weights at the ends would, of course, gradually increase, but the buoyancy would increase at the same time; and for that reason the excess of weight over buoyancy might remain constant while the ship was being filled out, and the longitudinal bending moment be of some value whether the vessel was fine or full. He had sought for some figures to corroborate this statement, and he found them in Vol. V., Part 7, of the Transactions of the Institution, in a communication from Mr. Piaud, Inspector-General of the Bureau Veritas, to Mr. Bergström's first paper. There a cargo steamer, 347 feet 9 inches long, 40 feet 4 inches in breadth, 19 feet 8½ inches draught, and ·44 in fineness, was filled out at the ends until her fineness became ·678. The influence of this filling out on the longitudinal bending moment, stresses in plating, etc., was most instructively shown in the following table, extracted from Mr. Piaud's communication :—

	Displacement. D.	Coefficient of Fineness.	Bending Moment M.	$\frac{L \times D}{M}$	Stress. Compression.	Stress. Tension.	
5	3471	·440	49677	24·28	3·29 keel	3·47 deck	On wave crest.
6	5343	·678	52129	35·61	3·42 keel	3·64 deck	
Increase	54 %	54 %	5 %	47 %	5 %	5 %	
5	3471	·440	22967	52·51	1·60 deck	1·52 keel	In wave hollow.
6	5343	·678	36129	51·38	2·52 deck	2·39 keel	
Increase	54 %	54 %	57 %	2 % decrease	57 %	57 %	

[NOTE.—The wood-cut (taken from a photograph) on the next page is inserted by the kind permission of the excellent new weekly illustrated paper called *Black and White*, a paper which devotes special attention to the illustration of yachting and of shipping. The insertion of the wood-cut is in connection with the query whether or not Mr. L. Piaud's trochoidal wave (Transactions, Vol. V., p. 178), referred to in Mr. Wm. Hök's remarks, does really give an adequate statement of the strains at sea, seeing that Mr. L. Piaud assumes the vessel to be both at rest and on an even keel. From Mr. Hök's remarks on page 422 taken in conjunction with the wood-cut, it is evident that the stresses at sea when ships are pitching, scending, and heaving among waves are no doubt different from those obtained by assuming the ship at rest on a wave crest or in a wave hollow.—EDITOR.]

These figures showed that while the displacement increased 54 per cent. by filling out the ends, on a wave crest the stresses increased only 5 per cent., but 57 per cent. when the ship was placed in the hollow. As the



ENGRAVED IN THE "BLACK AND WHITE" STUDIO.

S. "NORSEMAN."

stresses on the wave crest exceeded those in the hollow, only the former needed to be taken into account, showing very markedly that, with increase of displacement by filling out the ends, the bending moment and stresses increased very slightly. Displacement, for instance, and fineness might be doubled, but the bending moment and stresses might only increase 5 to 10 per cent. This was due to what he before explained about the relation between buoyancy and weight; and this circumstance explained why Lloyd's rules did not reduce the scantlings for finer ships; and if it was also remembered that, according to the freeboard tables, full ships loaded less deep than fine ones, it was very probable, as stresses increased with increase of draught—this being due to increase of buoyancy at the centre and increase of the excess of weight over buoyancy at the ends—that fine ships and full ships when similarly loaded would, practically speaking, have the same intensity of stress in the material subject to the effect of longitudinal stresses. This reasoning applied only to the statical conditions; the stresses would, no doubt, be very much different in fine and full ships if they took the dynamical conditions into consideration, as when the ship was pitching, 'scending, and heaving among the waves. He regretted he did not know anything definite about the effect on the stresses through these latter causes—in fact, no one knew. On page 395 Mr. Petree says:—"With regard to the equipment of anchors and chains, the load displacement alone should be the basis of comparison." This was not strictly correct, for the function of the anchors and chains was merely to resist the effect on the ship of sea, wind, and tide. If they had ships of dissimilar dimensions and form, but of equal displacements, the effect of these forces might be very different in each individual case. Therefore the displacement alone should not fix the size of anchors and chains. Some other factor should be taken into account; but how to do this in a practical way was very difficult to say without considerable expenditure of thought. The same remark held good in the case of estimating the engine power of ships. The actual weight of the ship or the displacement should not constitute the factor on which the power was based. The weight of the ship came only into play at accelerated speeds, or at the change from one speed to another. The effect of the weight disappeared when the ship was running at a constant speed, or when the acceleration was equal to nothing. Then the surface and form should be taken into account, and the power based on these factors, and not on the weight or displacement. He had just one more remark to make, which referred to what was said by the President.

The author was perfectly correct in saying that the longitudinal bending moment for similar bodies varied as the fourth power of the dimension. This was true for the elementary case of a beam as well as for the complicated form of a floating ship.

Mr. JOHN GRAVELL, of Bureau Veritas, said this was a very important paper. He thought the registration societies had a great deal to put up with in the complaints of many people, especially builders, who seem to think that registry rules are not based on proper lines; but as there exists so many different opinions amongst them, it is almost impossible to obtain any help from them. Of course, Lloyd's had one system and they (Bureau Veritas) had tried another, working principally upon the coefficient; they (Bureau Veritas) were supposed to provide a standard point, and when a vessel had a finer coefficient they had even departed from their rules to a certain extent to try and meet the special design and form of vessel. What more could they do? Mr. Petree in his paper implied that the rule to adjust the strength of scantlings of a vessel should be based upon her actual loaded weight and the trade for which she is required. He (Mr. Gravell) thought that was provided for by their rules, whether the vessel was required either for river purposes or sea purposes. At the present time some of these rules were undergoing revision to see if it was possible to improve them; in fact, this had been going on for several years, but so far they had found that very little alteration could be made, as, taking the actual coefficient at loaded draught and coefficient now used, it made very little difference in the scantlings.

The PRESIDENT believed it would be going rather outside what was usual if he said something on the question himself. He was in the chair and ought, perhaps, to be impartial, and have no views one way or another, but it would be affectation on this paper for him to do so, since it alluded to his own remarks in the opening address read at the commencement of the session. In the debate which took place at Hartlepool they had an expression of opinion from two of the representatives of Lloyd's Society. He did not wish to speak disrespectfully of what they said, but they all knew what officials would say when it was a question of making a reform. He supposed if they had to wait till the official mind saw fit to make a change or reform, from the penny postage stamp downwards, they would never be carried out. They listened with respect, but, so far as the remarks were an official disclaimer and in an official capacity, perhaps, with not a very great deal of attention. He took occasion during the debate to address to one gentlemen (Mr. McGlashan, not of Lloyd's) a question Mr. Yeoman had raised about the load-line,

but in the present he felt sure right would be done sooner or later. As regarded what was said at Hartlepool, one thing he omitted to mention, that one of the members of Lloyd's said that the displacement basis would be so difficult a thing and cause so much trouble to shipbuilders. But displacement was the first thing they got out in designing a ship; they knew it, at least approximately, before they knew the dimensions of a ship. Whatever difference of opinion there might be between different sets of persons, surely shipbuilders knew their own business and convenience best.

When they talked about displacement, and heard the remarks of Mr. Hök and what was said by the writer of the paper, the one particular point of a displacement basis seemed to him always overlooked. Those in favour of it had urged the effect upon the strains of the ship of the shape of the lines; but the principal factor in the displacement was the draught of water. At the time he was speaking of, nearly thirty years ago, he urged that they would never get to any proper understanding of the strains on ships unless they took into account the draught of water—the depth loaded. The thing was so self-evident. If they loaded deeply they must increase the stress, whereas if they did not put much weight into the vessel there was comparatively only half the strain. At that time the consensus of opinion in the country of shipowners, underwriters, and surveyors was decidedly against any fixing of the load-line. He (the President) remembered talking to the present chairman of Lloyd's, who himself had a very good record, he knew, in London, always allowing a freeboard of 3 inches to depth of hold, and he remembered his saying that he felt he was doing the right thing, and it was not for him to criticise what his neighbours were doing. This is the thought of the Poet Laureate—

> "And, because right is right, to follow right
> Were wisdom in the scorn of consequence."

Since then the shipping interest had been compelled to accept of legislation, mainly from the philanthropic efforts of Mr. Plimsoll. In his (the President's) humble opinion, if they had before this agitation faced the question, and recognised in the rules for scantlings that everything depended upon what the ship was carrying, all the heart-burnings and discussions which had since occurred would have been avoided, and the position at the present day been very much more satisfactory. Now, it was dwelt upon at the Hartlepool meeting that ships built in England and classed at Lloyd's or Veritas, that was, ships sailing under the English flag, had a load-line

fixed. It was commonly called "Lloyd's load-line." They spoke of Lloyd's "summer freeboard," and "winter freeboard," but he believed Lloyd's considered that load-line was fixed by rules of the Board of Trade, and that Lloyd's simply acted as agents of the Board of Trade in determining and requiring that load-line. Well, if one of these ships were sold to a foreign owner—Norwegian, German, Italian—not only might they in their own waters load as deeply as they liked, but load as deeply as they liked in English waters. Mr. Yeoman was asked to what extent this loading was carried; it was pressed home upon him, and he admitted as much as 7 per cent. A gentleman (Mr. Wm. Menzies) got up and said he had engined some steamers in Hartlepool that had gone in for over 20 per cent. extra loading.

Mr. HÖK—18 per cent.

The PRESIDENT—Possibly the calculation was wrong, but take it for the present at 10 per cent. only. When they considered that a vessel worth £40,000 would earn, roughly speaking, in the course of the year, £40,000 of gross freight, or perhaps less—and he supposed a ship on an average did not pay more than 10 per cent. dividend on the gross freight—they would see that £4,000 represented the amount of money that went into the pockets of the shareholders. If they increased the dead-weight cargo by only 10 per cent., 10 per cent. on £40,000 was £4,000. Now, he would be sorry to say that the additional loading of 10 per cent. would double the dividend, but that it would increase the dividend he was certain, and being himself interested in some foreign shipowning companies, he had come to the conclusion that the more satisfactory dividends paid by some of those companies were not altogether due to lower wages, but were considerably affected by the amount of cargo they were allowed to put on board. This was a question that affected engineers, shipbuilders, and shipowners, and also affected the working classes. They might be perfectly certain that if ships sailing under foreign flags paid better dividends than ships under the English flag, all experience went to show that the capitalist would not hesitate one moment as to which to put his investment. As with the shipping, so with the shipbuilding, it would be removed from England. They admitted foreign workmen into their shipyards, but he did not believe the foreign shipbuilders would take the higher paid English workmen into their employment. Mr. Yeoman was an authority, and his figures were not like the florid statements of Mr. Plimsoll, and he told them how he had seen the sailing ships of Hartlepool dwindle down from two hundred and fifty to twelve. He showed how,

at the present moment, the owning of steamers was beginning to be affected by the same rule, and he did think that the note of warning that Mr. Yeoman sounded ought not to be lightly cast aside. England had been called "the mistress of the seas, the queen of the colonies." He hoped she would remain so. They treated foreigners with a degree of generosity that astonished them. They allowed them to trade in their waters, and allowed them to ship in Australia and come to England, and made no sort of difference whatever, but when they allowed them to go further than that, and permitted them to carry trade under more favourable conditions than Englishmen themselves, he did think they were going too far. And he would like to point out this, it was very difficult for the English Government to interfere with foreign shipowners, but it was evident that if they chose to do it, and were not afraid of losing their customers, the registration societies could make the load-line the basis of classification, and in making the load-line the basis of classification they would be doing the most important thing in what they called making the displacement the basis of scantlings. He believed he must apologise for going out of the general course, and from the chair expressing any opinion upon the subject.

The SECRETARY intimated that Mr. Petree was unable to be present, and would have to reply by communication to the discussion.

The PRESIDENT said he was sure they were obliged to Mr. Petree, who hailed from this part of the country, although he was employed now in Messrs. Laird Brothers, of Birkenhead. He asked them to pass a vote of thanks to him by acclamation.

The vote was so accorded.

MR. PETREE'S REPLY.

The writer begs to express his indebtedness to the various speakers who took part in the discussion on "The Basis of Ships' Scantlings," in the course of which certain criticisms which invited reply have already been answered by other speakers.

Mr. Phillips, and subsequently Mr. Hök also, took exception to a suggestion as to regulating the floors solely by breadth of ship, and on this point the writer at once admits the force of the objection. "Chiefly," in place of "solely," would more correctly express the object of the paper in this respect. It may be mentioned in passing, that so far as the strain on cable is concerned, the surface above water affected by wind pressure

would chiefly consist of the area as seen "end on," and therefore would probably not amount to very much, except in ships of heavy square rig or unusual top-hamper. As regards the desirability of ordering material at the earliest possible stage, every practical shipbuilder will readily agree with Mr. Phillips; but he is, no doubt, fully aware that the preparation of at least a rough sheer draught (or model) must in every case precede even the ordering of material, and this at the same time provides the means of estimating displacement within reasonable limits. The remark that "until the vessel was practically designed and fully laid off nothing was known with any degree of accuracy of the displacement," is one in which few practical builders are likely to concur. Such may have been the case thirty or forty years ago, but the statement cannot in fairness be applied to any representative builders of to-day; in fact, the shipbuilder's guarantee of carrying capacity is virtually a guarantee of minimum displacement also, since (on a given price) it is contrary to his own interests to add weight to the remaining items—hull, machinery, and equipment.

To the query as to how many shipowners know or care about the displacement of their ships, as compared with carrying capacity, the obvious answer is, Very few. Nor need they know. A similar query might be asked:—How many shipowners know or care about the scantlings of their ships, so long as they are classed? For, of the three parties named by Mr. John as being concerned in the question of scantlings, the shipowner is certainly neither first nor second. Let the builder guarantee carrying capacity, etc., and the society grant a "class," and the shipowner is usually content to leave the question of scantlings to the first two parties.

As occasional remarks in the discussion seem to indicate that the speakers were at the moment regarding displacement as the *sole* basis for scantlings, it may be well to restate that except when equipment was referred to, the writer merely claimed recognition of displacement as the principal (not sole) factor.

With reference to the relation between displacement and bending moment, Messrs. McGlashan and Hök appear to have placed a more literal interpretation upon the writer's words than intended. Two extreme coefficients were instanced, to emphasise the principle in view, rather than the precise ratio. The formula for longitudinal moment,

$$M = \frac{L \times D}{C},$$

practically correct for closely parallel cases, illustrates the principle rather than the fact for a wider range. On this point the paper might perhaps have been more explicit. The results embodied in Mr. Hök's quotation

from Mr. Piaud's table in Vol. V., though differing to some extent from what might have been anticipated, show most clearly the importance of taking displacement into account in adjusting the scantlings to meet the the strains. Fuller investigation of this phase of the question would enable more definite conclusions to be reached than is possible from consideration of an isolated case.

Mr. Courtier-Dutton, as a Lloyd's surveyor, drew attention to the facility of checking the accuracy of the dimensions upon which the present numerals are based, and suggested probable difficulties in checking a displacement element. These difficulties, though not mentioned in detail, were anticipated by the writer, who freely admits that the present system is somewhat easier of application, especially to the surveyor. Whether the argument constitutes sufficient ground for retaining a faulty system is a matter of opinion, but the objection is not so serious as it may seem. Precise accuracy is not of vital importance. The use of a planimeter on the sheer draught would make very short work of such a calculation, and on the scrieve board itself the ordinates for checking actual areas at a few stations might be obtained almost as quickly as the half girths. Most builders would rightly object to submit a body plan, such a course being quite unnecessary, to say the least. The form of the vessel is private property; all that is required is the *volume* of displacement, regardless of form. Taking the ship on a level keel, a curve of sectional areas could be submitted simultaneously with total displacement, and the surveyor could check all or any one he might chose. In reply to the speaker's remarks as to load-line administration, the writer could not do better than repeat the concluding sentence of Mr. Macoll's speech. Coming next to the hypothetical case of materially increasing a (presumably "well-deck") ship's displacement, it is very doubtful whether anyone but the shipowner himself would regard it as a curious thing if the registry were to demand increased strength. Curious or not, such a demand would be perfectly reasonable, if the additional load were attended by additional strains on the structure, as it probably would be.

Mr. Hök questioned the accuracy of the statement that actual capacity represented the earning power of a ship. It may or may not, according to circumstances, but for the last fifty years such has been the theory of the English tonnage law, which has admittedly fulfilled its purpose better than any previous system. Dead-weight cargoes represent only one class, and are not always the most profitable in proportion to space occupied.

The writer's thanks are specially due to the President, who on his behalf, kindly explained to non-technical enquirers the principle of varia-

tions in longitudinal bending moment. The President's weighty remarks at the close of the discussion cannot fail to meet with unqualified approval. From the standpoint of the paper itself, however, it will be seen that merely making the load-line a condition of classification would not by any means satisfy the writer's claim for a displacement factor in regard to scantlings, though it would undoubtedly be a step in that direction. That step must sooner or later be taken in the interests of British shipping, and the sooner the better. The next step will be the association of a more or less definite displacement with that definite load-line.

COMMUNICATION FROM THE PRESIDENT (MR. WIGHAM RICHARDSON).

Mr. John Duckitt, Secretary,
North-East Coast Institution of Engineers and Shipbuilders.

DEAR SIR,—You advise me that exception has been taken to my remarks at our concluding meeting in the sense that the arguments of Messrs. Phillips and Courtier-Dutton were not answered. The said remarks were called forth by an allusion in Mr. J. Petree's paper to my opening address, in which I said:—

"Most of the vessels built in this country are classed at Lloyd's, and the apportionment of the material is regulated by their rules, which, it cannot be too often repeated, are unfortunately and unintentionally a premium on inferior models. Lloyd's rules for the framing, etc., of a ship are approximately based on the *girth* of the mid-ship section measured up *to the deck*, with some handicapping in favour of square bilges, while the plating, etc., is regulated by an approximation to the *surface*, also measured *to the deck*, and also subject to handicapping in favour of models of box-like form. The basis of these regulations is bad enough in itself, and it is made worse by the action of our Government, which fixed upon a maximum load-line beyond which British shipowners cannot load their vessels. This restriction practically does not apply to foreign steamers, not even when they load in British ports. In my position I cannot very well say all that I know about foreign steamers and their loading, but that they do load deeper than the regulation load-line is a matter of notoriety. We cannot doubt but that our shipbuilding colleagues who have been elected to the sub-committee of Lloyd's will take this matter up and see that it is put right, so far, at least, as Lloyd's are able to put it right. What I personally have always contended for is that the load-line should be a *condition of the classification*, as it now is with awning-decked steamers, and that if scantlings are to be based on the girth and

the surface, that the girth and the surface respectively should be taken to the load water-line and not to the deck, and that then what are called the numerals should be adjusted accordingly."

I find that Mr. Petrec has himself answered most of the points, but as I do not wish either Mr. Phillips or Mr. Courtier-Dutton to have any cause of complaint I will add a few lines. Mr. Phillips says that nothing has ever been *formulated*. This is probably because the principle should be first recognised; but the following, perhaps, will convey the bare outline of what has been advanced as one way at least of treating the matter.

If it be conceded that a ship of 10,000 tons gross register should have heavier scantlings than one of 5,000 tons, and of 5,000 tons again heavier than one of 100, it will probably be also conceded that as true and convenient a basis for classifying or grading the different sizes as could be hit upon would be the loaded weight of each ship, or, in other words, the loaded displacement. Whether you regard your vessel bumping against a quay, or a sea striking her, or the various hogging, sagging, wracking, and twisting strains to which she will be subjected, you will find it difficult to hit upon a fairer basis of comparison. It is a truer basis of comparison than Lloyd's present practice, which hardly takes into account the fulness of *the model*, nor, what is still more important, the *draught of water*, except in an indirect way in small allowances for freeboard and in special types such as awning-decked steamers.

The alteration proposed hinges mainly on the question of load-line. Mr. McGlashan said Lloyd's cannot make the load-line a condition of classification on account of the competition of other registries. This, I trust, is not the view taken by Lloyd's Committee.

The alterations to the present system need not be very great. Let us take the tables beginning with—

G. and S. 1. Frames, Reverse Bars, etc.—The principle of basing these on their own length would be improved by also taking into account the weight the ship has to carry. To meet this, in lieu of the *half girth* + the *half beam* + the *depth*, take the whole girth measured to the *water-line*,* and rectify the column of scantlings. Our object is not to reduce scantlings, and therefore the numerals must be rectified. The floors, bulkheads, and pillars might follow the same numerals, or they could be otherwise treated.

G. and S. 4. Beams.—The scantlings of these, depending on their own length, need not be altered.

* In the case of a large side above the water-line, provide for efficient stiffening.

G. 8. Riveting.—This need not be altered.

G. and S. 2, 3, 5, and 6.—The numerals in these tables are now based on the product of the numerals in Table G. and S. 1. and the length of the ship. Under the proposed system there are two courses open :—

(*a*) To take the amended numerals of Table G. or S. 1. (*i.e.*, the length of the whole girth measured to the load-line) and multiply the same by the vessel's length. This would be following Lloyd's present practice, the alterations to Tables G. and S. 1. being embodied.

(*b*) To multiply the load displacement in tons by the length of the vessel (in feet), and divide by the depth of the girder. The depth rather than the breadth of beam should be taken, because in ships the depth is almost always the weakest cross measurement of the girder.

The difference between the two proposals (*a*) and (*b*) is very essential. Mr. Courtier-Dutton quoted the authority of the late William John. Though not always agreeing with that gentleman, I may note that he wrote as follows :—

"In the calculations which I have laid before you, the tension per square inch on the upper works of a vessel of 3,000 tons appears to be one and a half times as great as that on a ship of 1,500 tons, twice as great as on a 700 ton ship, and five times as great as in a little vessel of 100 tons of the same proportionate dimensions."—*Inst. Naval Architects*, Vol. XV.

This is only what is to be expected if the scantlings are regulated by Lloyd's present rules. It would also be the case if the system (*a*) as above were adopted.

By the formula (*b*) a very much nearer relative approximation would be attained of the strength required to resist the various bending and twisting strains to which the ship would be subjected. It would have the effect of adding relatively to the scantlings of large ships. I believe that since the losses of the large steamers in the Atlantic trade about twenty years ago, experience has led Lloyd's Committee to anticipate this by increasing considerably the scantlings of large steamers in various details. If the committee did not see its way to adopt in its entirety the truer formula (*b*), a half-way house can always be found either by varying the power of any factor, or by allowing a certain constant (a sixteenth or a twentieth of an inch or whatever it might be) for corrosion, or by modifying the scantling tables. At the present time if the so-called numerals

are taken to represent successive steps of strains, the strengths of the frame angles and reverse bars (if their size as well as their weight be calculated) increase in a much greater ratio.*

In any case, however, the change will be nothing like the leap which Lloyd's took some twenty years ago. *Then* they based their tables for scantlings upon the under-deck register tonnage, while the Veritas, if I recollect rightly, based theirs on the length, breadth, and depth multiplied together. Both societies, in fact, varied their scantlings as the cube of the increase in size, or, as we may say, as the *cube of the dimension*. It was a huge leap down to go from this to the first power (as regards the framework), and as the second power (as regards the plating and stringers), or in other words to alter the basis of the framework scantlings from the tonnage to the cube root of the tonnage. And yet, this is what it amounted to as between vessels of the same proportions. To anyone with an engineering or mathematical training, the difference between the first power and the cube is something altogether radical and enormous. Probably the committee at Lloyd's never knew exactly what was the nature of the change which was being effected, but I shrewdly suspected that some of the staff knew better, and began to realise in the face of what was being built at that epoch that it would not do to attempt to build Atlantic liners, let alone Great Easterns, if they calculated the scantlings advancing by the cube of the dimension. However this may be, I myself never heard, either officially or semi-officially, any other reason given for the change save this, that it was impossible to tell until the ship was completed and measured what the under-deck register tonnage would exactly turn out to be!

I will now refer to Mr. Courtier-Dutton's objections. He seems to

* It would take far more than these few pages to go thoroughly into the question of scantlings. It is often imagined that the strengths increase *pari passu* with the numerals. But take for example the table for steel frames and reverse bars.

Numerals.	Spacing.	Frames.	Weight per Foot.
31 to 37	20 ins.	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$	4·04 lbs.
115 to 120	26 „	$7 \times 3\frac{1}{2} \times \frac{10}{16}$	17·00 „

	Reverse Bars.	Weight per Foot.
31 to 37	$2\frac{1}{4} \times 2\frac{1}{4} \times \frac{5}{16}$	3·61 lbs.
115 to 120	$4\frac{1}{2} \times 4 \times \frac{10}{16}$	13·60 „

Adding together the weights per foot of the frames and of the reverse bars we have this sort of proportion:—

Average Numeral ...	34	Weight ...	7·65 lbs.
„ „ ...	117½	„ ...	30·60 „

By which it would seem that the weight increases in a somewhat greater ratio than do the numerals; but as the depth of the Z is in the one case from 2½ to 3 inches and in the other from 7 to 7½ inches, it is evident that the strength of the framework increases in a ratio altogether different from the numerals.

I merely note this point without discussing it.

think that the displacement basis would be inconvenient to the builder and cause delay. This impression also seems to be in the mind of Lloyd's chief surveyor. Probably it is the exact opposite of the fact. In almost every case when a builder designs a ship, whether to carry cargo or not, he has to estimate the displacement before he even knows the dimensions. Wherefore, in submitting a section to Lloyd's it would evidently save time, and in nowise cause delay, were the builders required simply to give the displacement, in lieu of some of the other particulars required.

Now, it is evident that no respectable firm would ever dream of misrepresenting the displacement, but of course the surveyors for the sake of good order should be placed in a position to check it readily. This could be done without even submitting the lines of the vessel, which may rightly be considered to be the exclusive property of the builder. All that he would be required to do would be to submit before the vessel is in frames, say five sections as shown (Figs. 1, 2, 3, Plate LV.), the area of which he must undertake *not to exceed* in the ship to be built. These areas could be checked from the scrieves on the boards, or otherwise the builder might be called upon to paint these frames a different colour, if required, and to make a framework of laths (Fig. 1, Plate LV.), which would be set up against each of the five frames successively. The surveyor could measure this frame when laid on the ground. Such assistance to the surveyor would be readily granted in any yard, and the five sections would be ample to give an approximate displacement. In fact the displacement deduced from them might be called the *displacement for the purpose of classification*. I think Mr. Courtier-Dutton will allow that there is nothing alarming about this.

Cases may occur in which the builder is unwilling or unable either to give either the displacement or the load-line. In such exceptional cases the committee would naturally form their own opinion, and assign a maximum coefficient of fulness and a load-line.

Lastly, there is Mr. Courtier-Dutton's objection as to the freeboard. This deserves our best attention, for Mr. Courtier-Dutton is known to have had a special experience herein. Now, it must be remembered that the present Load-Line Act, 53 Vict , cap. 9, 1890, is avowedly based upon surplus buoyancy, and the under-deck tonnage has been taken in default of knowing the displacement. It moreover gives powers to the Board of Trade to modify the table, and on a request from Lloyd's or Veritas, or from any similar corporation, the Board would doubtless allow displacement to be taken in lieu of under-deck tonnage.

Even, however, if following literally the present complicated practice, there is surely no real difficulty. Builders now either take out the new tonnage and fix the freeboard at the time the ship is designed, as my firm does, or they leave it to be determined by the surveyor after the under-deck register tonnage has been ascertained.

Suppose now, firstly, that the assigned freeboard agrees with the designed load-line, there is evidently no harm done.

Secondly, that the assigned freeboard is less than desired in the builder's design, evidently again no one can complain.

Thirdly, that the assigned freeboard is more than the builder designed to give. In this case, as now, the builder would find he had over-estimated what the Act allows, and he would in so far suffer, as he does now, but with the additional suffering of having made his vessel rather heavier than strictly required for the class. This last case would only happen, however, to those builders who either have not a staff sufficient to make calculations, or whose staff made an error in the calculations. So that, even if the tonnage table continued to be enforced without the obvious substitution of displacement for tonnage, although the builders might have to bear this responsibility, it is not so great as the many guarantees which they now undertake regarding capacity, dead-weight, speed, etc.

Lastly, Mr. Courtier-Dutton said that at present owners may stiffen up the bridge bulkhead and other minor additions, and get an increased displacement without increasing the general scantlings of the hull. In reply to this, we may submit that if the committee are justified in allowing these alterations now, they would be equally so justified under the new system. If it be right in the one case it must be equally right in the other. *If* it be right to allow a vessel built with any given scantlings to load deeper than her originally designed draught without increasing her general scantlings, the special rule or system which may have been employed to determine her scantlings cannot affect the rightness or the wrongness of such a concession of diminished freeboard. But under the new system we might expect a more liberal freeboard to be generally adopted, since an addition to the height above the water would not involve an increase in the scantlings. In some cases it would even reduce the scantlings.

I trust that the members of our Institution will excuse this long letter which I have written, so as to avoid every semblance of a want of courtesy, or of a hesitation fairly to meet the arguments advanced in a fair discussion.

Mr. Hök has suggested that a committee of our Institution be appointed to take this subject in hand in a more exhaustive manner, and I propose to lay his suggestion before our Council.

Yours truly,

WIGHAM RICHARDSON,

President.

CLOSING BUSINESS.

ALTERATION OF CONSTITUTION AND BYE-LAWS.

The PRESIDENT, on behalf of the Council, moved that the following alterations be made in the Articles of Constitution and the Bye-Laws:—

The proposed alterations are printed in italics.

CONSTITUTION.

X.—Paragraph 3 to read as follows:—

The retiring Vice-Presidents *shall be eligible for re-election.* The retiring Councilmen shall not be eligible for re-election to the same offices until after an interval of one year, but shall be eligible for election to any other office.

BYE-LAWS.

31.—The following Sub-Committees shall be appointed annually *at the first meeting* of the Council *in each session:*—(1) A Finance Committee, to consist of seven persons, viz.: one Past-President or Vice-President, who shall be Chairman; five Councilmen, and the Honorary Treasurer of the Institution; three of whom shall form a quorum. The Treasurer shall be empowered to pay all amounts due from the Institution which are under two pounds. All amounts of two pounds and upwards shall be paid by cheque, signed by the Chairman of the Finance Committee (or in his absence, by the President or a Past-President), the Secretary, and the Honorary Treasurer. (2) A Reading Committee, to consist of six members of Council. *No member who has served on this Committee for three years in succession shall be eligible for re-election until after an interval of one year.* (3) *A Library Committee, in accordance with Library Bye-Laws Nos.* 1 *and* 3.

35.—Old Rule to be rescinded and the following to be inserted:—*The Secretary shall send to each speaker as soon as possible after a General Meeting a copy in manuscript of the speaker's own remarks for correction. This copy must be returned to the Secretary within four days. A printed proof will also be sent to each speaker for further revision; this must be returned to the Secretary within three days, otherwise it will be deemed correct, and printed off after receiving verbal corrections.*

36.—Add after the word "Secretary" *and must be approved by the Reading Committee.*

New Bye-Law to be numbered 44 :—

The capital, stock, and funds of this Institution shall be vested in the names of three Trustees, to be elected from time to time as vacancies occur by the members of the Institution at a General Meeting called for that purpose. All mortgages and other securities shall be taken in the names of such Trustees; and on any new appointment the funds shall vest in the newly-appointed Trustee or Trustees jointly with the continuing or remaining Trustee or Trustees.

The present Bye-Law No. 44 shall be numbered 45.

This was seconded by Mr. HUGH MACOLL, and carried unanimously.

APPOINTMENT OF AUDITOR.

Mr. HUGH MACOLL had much pleasure in moving the re-election of Mr. R. W. SISSON as Auditor. He had given a very good account of their finances last year, and he hoped he would be able to do so again.

Mr. B. G. NICHOL seconded the proposal, which was accepted.

ELECTION OF OFFICE-BEARERS.

The following was declared to be the result of the ballot to fill the vacancies on the Council of the Institution:—

President—MR. WIGHAM RICHARDSON. (Re-elected.)
Vice-Presidents—MESSRS. J. R. FOTHERGILL, JOHN PRICE, and JOHN TWEEDY.
Hon. Treasurer—MR. B. G. NICHOL. (Re-elected.)
Council—MESSRS. HUGH MACOLL, D. B. MORISON, J. W. REED, M. SANDISON, and R. L. WEIGHTON.

The PRESIDENT stated that Mr. Johan Johnson had resigned his seat on the Council, and the Council had elected Mr. G. E. MACARTHY to fill his place.

THE PRESIDENT.

The PRESIDENT said he wished to thank the members of the Institution for their great indulgence to him. Circumstances had prevented him attending very well during the past year, and he had not received one word of reproach. They had, moreover, filled up his cup by electing him a second time. He hoped the next year would be as successful as that now closing, and that they would all live to meet in health and happiness when the autumn came round.

Mr. WM. BOYD said he really thought the session could not be allowed to conclude without a recognition of Mr. Richardson's good wishes towards this Institution during his year of office. It was all very well for him to say he did not want any resolution of this kind proposed, but

they had seen what he did at the beginning and end of the session, and if unavoidable circumstances had not occurred, he would have given them the benefit of his presence in the chair during the whole of the session. Although he had not been able to be present very much during the last year, still they must not allow him to run away with the idea they had not valued, to begin with, his inaugural address and general superintendence exercised over that Institution during his year of office, otherwise he might think he had been grudgingly elected for another year. He (Mr. Boyd) having presided over the Council meeting when his nomination was proposed had much pleasure in assuring him that a very contrary feeling strongly prevailed, and he trusted the President would allow him to move this vote of thanks.

Mr. F. C. MARSHALL had very great pleasure in seconding the vote of thanks to their President, and though he had not the pleasure of being at the meeting of the Council when he was proposed for the second time, he most cordially endorsed his re-election. Mr. Richardson had had a great many journeyings to and fro, and that, from sad experience, he knew also took up a very great amount of time, and interfered with the occupation of such an office.

Mr. BOYD put the resolution to the meeting, and it was cordially adopted.

The PRESIDENT—I thank you very much, gentlemen.

The seventh session was then closed.

VISIT TO MESSRS. THE WEARDALE IRON AND COAL COMPANY'S WORKS AT SPENNYMOOR.

The Council of the Institution having received a special invitation from Messrs. The Weardale Iron and Coal Company to visit their Tudhoe works and collieries, it was arranged that the visit should take place on Wednesday, June 3rd. The members left the Central Railway Station, Newcastle-upon-Tyne, at 9·45 a.m. and arrived at Spennymoor at 11 a.m., where they were received by the manager, Mr. Henry William Hollis, and staff, and conducted through the iron and steel works. The two blast furnaces were first visited. These are 85 feet high from hearth to platform and 24 feet 6 inches in diameter at the boshes, each having a capacity of 22,000 cubic feet. Each furnace is tapped every six hours. The hot blast, which enters each furnace by six tuyeres, is generated in two Cowper regenerator stoves. These are 63 feet high and 23 feet in diameter. They are changed every two hours from gas to blast and *vice versâ*. There are three blowing engines to work the blast, with blowing cylinders 84 inches diameter and steam cylinders 40 inches diameter, by 5 feet stroke, the pressure of the blast being about 5 lbs. to the square inch. The gases generated within the furnaces are used to drive four triple-flued internally-fired boilers 8 feet diameter by 30 feet long, working at a pressure of 90 lbs. on the square inch. All the steel produced at the works is made from the Spanish ores; but, as the blast furnaces have to produce pig iron both for the steel and iron works and for sale, two kinds of pig are turned out, viz., hematite pig from the Spanish ores (obtained from the Rubio and Campanil Mines, Bilbao) for steel and iron, and Weardale pig for the iron works and general market. The analyses of these pigs are as follows:—

	Weardale.		Hematite.
Iron (by difference)	91·490	...	92·428
Combined carbon	·430	...	·260
Graphic do.	3·640	...	3·800
Manganese	2·370	...	1·290
Silicon	1·980	...	2·160
Sulphur	·020	...	·023
Phosphorus	·070	...	·039
	100·000	...	100·000

By the manager of this department matters were so arranged that one of the furnaces was tapped on the arrival of the members.

The puddling furnaces were next visited. These are forty in number, arranged in bays and worked in pairs. A single furnace has a capacity of 4½ cwts. per charge; a double furnace, of which there are three, with mechanical puddling, has a capacity of 12 cwts. per charge, and each can take six charges per shift, of which there are two per day. There are two ball furnaces in which the finest bar iron is made, two steam hammers, two helves, and shears to cut the puddled bars for the rolling mills.

In proceeding to the Siemens-Martin steel works the old Bessemer steel works were visited. It was here the first license issued in connection with the Bessemer patent was worked. This was in the year 1861. The original plant consisted of four 50 cwt. converters, with blowing engine having steam cylinders 32 inches diameter and blowing cylinders 42 inches diameter, hydraulic ladle-lifting cranes, furnaces, and cupolas complete. These are now abandoned, and have been substituted by the Siemens-Martin steel works. Seven furnaces are erected at Tudhoe, five of 20 tons and two of 12 tons capacity. The molten steel is run into either slabs or ingots, varying in weight from 1½ cwt. to 6 tons. During the visit two furnaces were tapped, and the following analysis of the metal may be of interest:—

	Weardale Steel.
Metallic iron	99·163
Carbon	·170
Silicon	·009
Manganese	·600
Sulphur	·020
Phosphorus	·038
	100·000

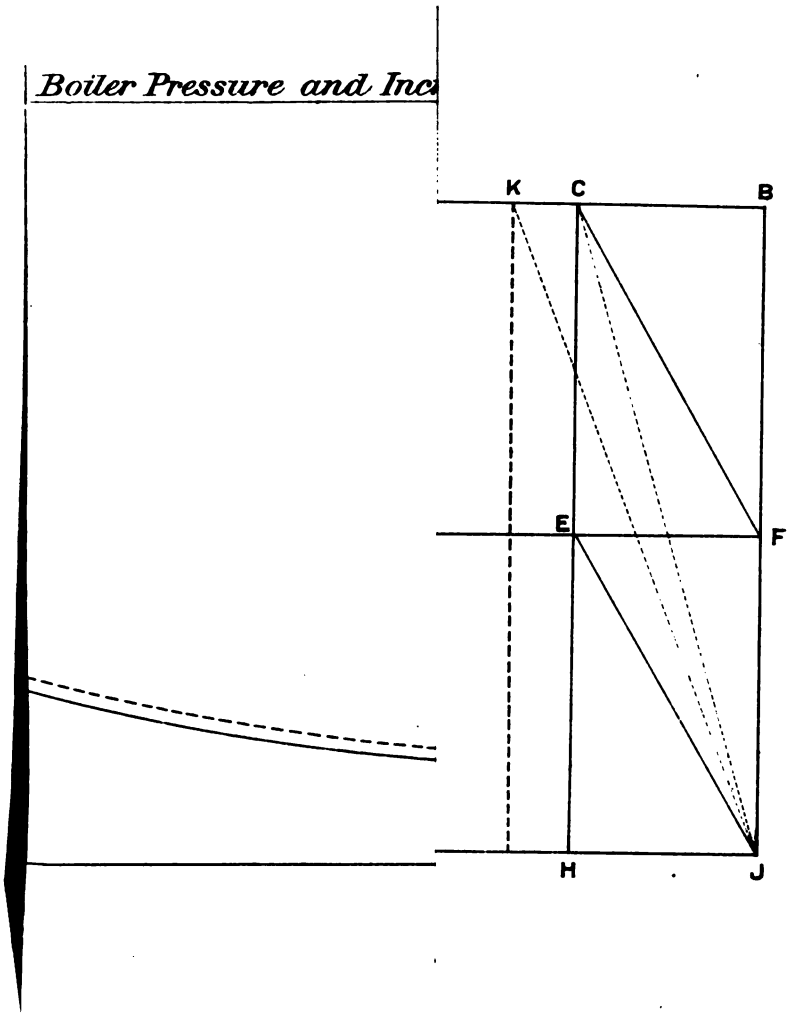
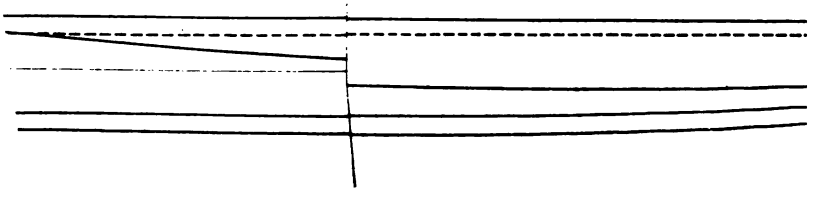
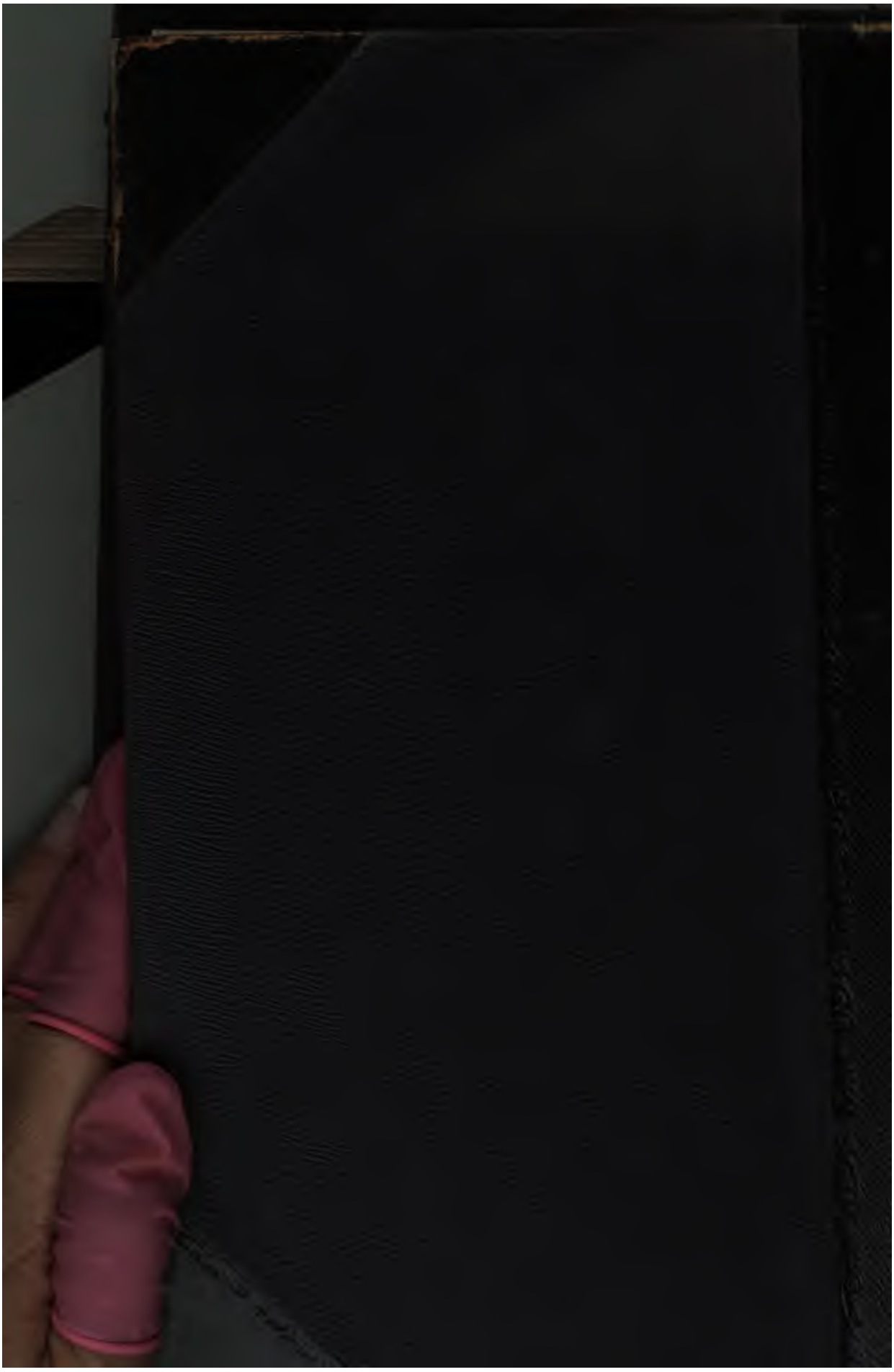
The testing house was next visited. In this there are two testing machines, one to work up to a strain of 100 tons and the other 50 tons. A number of test pieces were broken and the fracture examined, which proved of considerable interest.

Attention was then called to the rolling mills, where an ingot of steel weighing over 2½ tons was rolled out to a plate 1 inch in thickness in a few minutes.

The members then retired to a sumptuous luncheon provided by the company in the St. Andrew's Hall, Spennymoor. After luncheon the Tudhoe Colliery, coke ovens, and brickworks were visited, and many of the visitors descended into the pit workings.

At Tudhoe Colliery there are three shafts sunk to the Brockwell Seam, a depth of 88 fathoms. Two of these are used for drawing coal and one

for ventilation. The daily output is 1,400 tons, the produce of three seams, viz. :—the Hutton, Busty, and Brockwell. A good deal of the coal is made into coke, for the manufacture of which there are 425 Beehive ovens used, which produce 149,000 tons per annum, or about 3000 tons per week. Adjoining the colliery are extensive fire-brick wcrks, at which are manufactured annually 2½ millions of bricks and 600 tons of lumps. There are altogether about 1,420 men and boys employed.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